STINFO COPY
United States Air Force
Research Laboratory

A NET CENTRIC COLLABORATIVE SUPPORT SYSTEM CONCEPT: A PRELIMINARY INVESTIGATION

ROBERT EGGLESTON

WARFIGHTER INTERFACE DIVISION
HUMAN EFFECTIVENESS DIRECTORATE
WRIGHT-PATTERSON AFB OH 45433

RANDALL WHITAKER

NORTHROP GRUMMAN INFORMATION TECHNOLOGIES
DAYTON OH 45433

JANUARY 2004

20040422 037

FINAL REPORT FOR THE PERIOD MARCH 1997 TO OCTOBER 1997

Human Effectiveness Directorate
Warfighter Interface Division
2255 H Street
Wright-Patterson AFB OH 45433-7022

NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from the Air Force Research Laboratory. Additional copies may be purchased from:

<div align="center">

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

</div>

Federal Government agencies and their contractors registered with the Defense Technical Information Center should direct requests for copies of this report to:

<div align="center">

Defense Technical Information Center
8725 John J. Kingman Road, Suite 0944
Ft. Belvoir, Virginia 22060-6218

</div>

TECHNICAL REVIEW AND APPROVAL

<div align="center">

AFRL-HE-WP-TR-2003-0102

</div>

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

//Signed//

MARIS M. VIKMANIS
Chief, Warfighter Interface Division
Air Force Research Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 2004	Final, March 1997 - October 1997

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
A Net Centric Collaborative Support System Concept: A Preliminary Investigation	PR: 2313
6. AUTHOR(S)	TA: CH
	WU: 73
*Robert Eggleston, **Randall Whitaker	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION
**Northrop Grumman Information Technologies Dayton OH 45433	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING
*Air Force Research Laboratory, Human Effectiveness Directorate Warfighter Interface Division Air Force Materiel Command Wright-Patterson AFB OH 45433-7022	AFRL-HE-WP-TR-2003-0102

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for Public Release; distribution is unlimited	

13. ABSTRACT *(Maximum 200 words)*
This study is an initial attempt to investigate the emerging net-centric warfare concept from the perspective of the user interface and team performance. The report lays out a conceptual framework as the basis for establishing a scientific foundation for user interface design in the enterprise system context. This framework includes a joint functional layer added to the information technology (IT) infrastructure. Design requirements for this layer of the collaborative interface are derived from principles of Cognitive Systems Engineering and characteristics of human expertise. In conjunction with the theoretical development, an experimental testbed is that it includes a heterogeneous array of computer platforms and commercial off-the-shelf (COTS) products. In this study, the testbed was used to host a BMC4I scenario that required joint collaborative work across Air Force and Army units. This military scenario provided an additional means to uncover other issues important to user interface design in an enterprise IT environment. The report the user interface design framework, describes the research testbed, and discusses lessons learned from the informal experimentation of distributed teamwork using the BMC4I scenario.

14. SUBJECT TERMS		15. NUMBER OF PAGES
User Interface Design, Collaborative Work, Distributed Teamwork, Collaborative Interface		
		16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

This study is an initial attempt to investigate the emerging net-centric warfare concept from the perspective of the user interface and team performance. Net-centric warfare is enabled by advanced Information technology (IT) configured as an enterprise system of systems. The enterprise system concept supports the inclusion of a diverse set of databases and application software that all contributed to the operational work processes contained in a battlespace management, command, control, computers, and intelligence (BMC4I) system. Because this form of enterprise system includes a wide variety of applications produced by different vendors, it raises new challenges for user interface design to support coordinated and distributed teamwork: Do we need a new conceptualization of the user interface to support distributed collaborative work? How can the interface itself help provide a common work focus when many different applications must be used in work? How does the user interface relate to distributed teamwork? This study addresses these questions.

The report lays out a conceptual framework as the basis for establishing a scientific foundation for user interface design in the enterprise system context. This framework includes a joint functional layer added to the information technology (IT) infrastructure. Design requirements for this layer of the collaborative interface are derived from principles of Cognitive Systems Engineering and principles derived from the study of human expertise. The conceptual framework for the user interface is described in detail.

In conjunction with the theoretical development, an experimental tested was created to empirically investigate user interface issues associated with distributed teamwork in an enterprise IT context. An important characteristic of the testbed is that it includes a heterogeneous array of computer platforms and commercial off-the-shelf (COTS) products. In this study, the testbed was used to host a BMC4I scenario that required joint collaborative work across Air Force and Army units. This military scenario provided an additional means to uncover other issues important to user interface design in an enterprise IT environment.

The report summarizes the conceptual framework for collaborative user interface design, a description of the enterprise system research testbed, and a discussion of the lessons learned from the informal experimentation of distributed teamwork using the BMC4I scenario.

1

I.
INTRODUCTION:
TEAMWORK THROUGH EMERGING INFORMATION TECHNOLOGY

Teamwork and coordinated operations have always been significant factors in successful military operations. Recent experiences from operations in Desert Storm and subsequent large-scale military exercises have provided early demonstrations of how advances in technology make it possible to achieve unprecedented levels of teamwork, including a more dynamic and fluid form of coordination and cooperation. We are entering an era where the extent of connectivity of people, information, tools, and imagery extends the concept of a battlefield to include remotely located specialist and commanders, including the Commander-in-Chief even when he is in the White House. The Commander-in-Chief, for example, now has the ability to interact directly with a specific pilot in a mission, observing in near real-time many aspects of the local situation from a single warfighter's perspective. This capability is being made possible in large part by emerging advances in information technology (IT). Some believe that the changes made possible by this enabling technology will have a profound effect on future warfare.

Increased connectivity in both form and quantity makes it possible for the military to consider highly interactive, distributed organizational structures. New working organizations can be created quickly to meet evolving contingencies. Specialists residing in the USA may be active members of various teams in a theater-based Air Operations Center (AOC). Or an AOC may be "virtual," with all its staff geographically distributed, thus providing an extended version of the emerging concept of "reachback." Some are even contemplating the possibility of dynamically reconfiguring joint operations while actors are simultaneously being engaged in the execution of operational activities. A vast array of possibilities for how to improve fast-paced, coordinated military operations is being contemplated. All of them have implications for organization structure, team processes, and human integration with information technology.

Operational concepts for warfare in the future are not settled. There are many possibilities, and we can expect them to change more-or-less continuously over time. Indeed, IT itself even makes it possible to change an operational concept more completely and faster than ever before. However, for initial planning purposes, Joint Vision 2010 offers a top level view of the emerging military operational concepts. It outlines four concepts: (1) dominant maneuver, (2) precision engagement, (3) focused logistics, and (4) full-dimensional protection. IT is a critical enabling technology needed to realize these concepts in practice. Practical considerations that must also be taken into account include leaner DoD budgets, reduced staffing, and a desire to minimize the "foot print" of our military forces in the vicinity of the physical engagement region.

While IT is expected to make new ways of operating possible, it brings with it the need to develop a deeper and in some cases new understanding of the requirements for inter and intra team organization and coordination, as well as the need for new requirements for how best to integrate humans with the IT media and embedded tools. Organizational processes supporting team and collaborative work are interactive with IT. The most visible point of interaction is at the user interface.

This final report covers work being accomplished under the New World Vista initiative in the area of human interfaces. It describes the development of a research program we have undertaken to investigate user interface requirements for an information technology system, in terms directly related to interface consequences on individual and teamwork processes and outcome performance. The purpose of this research is to provide a scientific foundation for establishing design requirements for the *joint functional interface* through which teams engage their IT support in a highly distributed and interconnected workspace. This work is conducted under the aegis of the Collaborative Systems Technology Laboratory (CSTL), Armstrong Laboratory (AFRL/CFHI).

Section II will provide a detailed discussion of the conceptual infrastructure activities aimed at building the theoretical foundations for ongoing CSTL research. This will provide a summary of relevant work, a synopsis of critical issues, and an appraisal of how CSTL can further the state of the theoretical art. Section III will similarly discuss the last 6 months' CSTL physical infrastructure ramp-up and introduce an initial simulation exercise illustrating how IT constraints affect team performance in a simulated BMC4I scenario.

II.
PROJECT DEVELOPMENT:
CONCEPTUAL INFRASTRUCTURE ACTIVITIES

The goal of this research is to establish a scientific foundation for the development of design principles and information requirements applicable to the team interface problems related to the effective exploitation of information technology (IT) in military operations. To achieve this goal we have developed an empirically based research program that is capable of deriving design principles from theories of individual and team expertise. Design principles emerge based on a mapping from performance theory to performance modeling to principles of representation for the individual/team interface with IT.

In Section A, we shall identify the problems underlying theoretical deficiencies in addressing interface issues to date. Section B will address broad CSTL methodology by specifying the process orientation of our research agenda and introducing a model for progressively refining interface concepts and applications. Section C will present an initial CSTL interface model which maps the functional interrelationships among users and technologies. Section D will specify key features for a model of team performance, as well as explaining how CSTL will adopt a skills perspective in analyzing team IT issues. Section E will continue this performance-oriented development by characterizing expertise as the focal concept in such a skills perspective. Finally, in Section F, we shall introduce a preliminary workspace model drawing on the theoretical elements already introduced. This workspace model provides a tractable framework for linking individual and team performance in a manner amenable to empirical research.

A. Problem Statement

Our research goals entail attention to two critical themes: a) the utility of IT support for teams operating as coherent and effective units (as opposed to just any collection of individuals); and b) the unavoidable dependency of task performance evaluation on characteristics of the work situation and activities for which such performance is assessed. In this section, we shall outline what we see as the problematical state of the art in interface research and development, and we shall frame the perceived problems with regard to these themes.

Most generally, we can state that the working knowledge required to effect good interfaces is not yet in hand. Regardless of the mass of literature dedicated to interface design and usability, there is still no universal or uniform theoretical foundation from which we can readily draw. Although there are numerous "tips" and "recommendations" derived from experiment and experience, these do not sum up to a cohesive practical substitute for such theory. Even taken in relative isolation, these practical results are not guaranteed to be universally applicable. It has often proven difficult to consistently apply the available representation principles for single user interfaces due to conflicts when a

4

designer tries to achieve a set of information delivery goals. In some instances, published guidelines that express representation principles offer conflicting positions (e.g. Woodson & Conover, 1964, on the use of color). These problems exist in spite of the fact that many of the design principles are supported by a history of sound scientific research on human functional capacities (e.g. Wickens & Carswell, 1995; Teichner & Krebs, 1974).

There is a corresponding immaturity in this area with respect to our critical themes. Recent reviews of interface design principles and their foundations (e.g., Bennett & Flach, 1992; Bennett, Nagy, & Flach, 1997) confirm that work to date does not provide sound design principles for interfaces specifically geared to support teamwork -- especially those interfaces implemented for the sort of spatially distributed organizational structures which future military operations will require. Recent efforts aimed at deriving interface design principles have shown increased awareness of the need to relate human processing to task factors. The problems in addressing this need from a traditional information-processing framework will be discussed in more detail below. The more pragmatic (and less problematical) body of work labeled cognitive engineering or cognitive systems engineering (e.g. Rasmussen, 1986; Rasmussen *et al.*, 1994; Flach & Dominguez, 1995; Woods, 1991; Woods & Roth, 1988) offers us a more task-sensitive framework for pursuing our objectives.

Typical approaches to the development of principles for interface design have conceived of the interface as consisting of an information channel and a control channel. This is well illustrated by Norman's (1986) "bridges" model for two-way interaction between user and computer. Such a characterization prioritizes information and information processing, resulting in a strong linkage between interface research and analyses of the sensory, perceptual, and cognitive capabilities of humans. Even within this mainstream of interface research and development, specific principles of information representation to support teamwork have only been sketchily addressed.

Based on our analysis, we believe that current interface design principles are deficient for specifying "good practice" in generating and evaluating mechanisms and procedures enabling teams (as teams) to utilize information technologies. A primary reason for this deficiency is a demonstrable bias toward addressing IT usage solely in terms of individuals (as opposed to teams or other collectives). In turn, this individual bias can be traced to two operant historical factors -- one involving theoretical stance and the other involving the perspective adopted in assessing interaction between human and machine. Let us now introduce these factors in turn.

1. Limitations of an information processing perspective

The first such factor (theoretical stance) is the cognitivistic / symbol-oriented / information processing paradigm which for over three decades has dominated research labeled as (e.g.) artificial intelligence (AI), cognitive psychology, and cognitive science. This perspective's default scope of reference is "cognition", viewed as an input-output

symbolic process. As a result, this orientation necessarily frames phenomena with primary respect to information resources and data streams whose nexus is the individual. The "work" or the "task" typically is addressed somewhat one-dimensionally in terms of such symbolic processing. Additionally, the ascription of symbolic processing to the personal faculties of a given human lends this approach a necessarily individual focus.

The extension of this individualistic orientation to information processing in groups or teams has been attempted, but the results to date typically end with vague allusions to "distributed cognition" or "group cognition." Apparently the assumption is that principles based on human information processing apply equally well to teams and individuals. Such allusions are admittedly enticing, but their utility is still questionable. For one thing, simplistic application of an information processing perspective to teams fails to escape the constraint that it can only address task performance to the extent salient factors can be expressed in terms of data streams and symbolic manipulations. Furthermore, because such terminology is illuminating only to the extent it expresses the manner in which a team operates as a whole, it is potentially blind to interactivity among team members. Finally, this sort of nomenclature has not yet achieved any uniformity of definition or connotation among those who invoke it.

Even if a cohesive theory of "group cognition" were available, its information processing orientation would still be problematical for our research goals. Informational parameters determine task performance only to the extent that the task is comprehensively delineated in terms of processing information. This means that such a perspective can fall short in addressing such issues as team coordination, joint work, and work sharing. For example, factors such as contextual dependencies and operational biases fall outside the scope of such an approach unless they can be somehow cataloged and coded as processable data themselves. Thus, even if one were to believe that all salient task performance factors could be symbolized, he / she would still face the prospect of an endlessly receding horizon of data which must be subsumed to model and manipulate a given work domain. Furthermore, some factors of demonstrable salience to task performance (e.g., fatigue, stress) lie entirely outside the scope of an information processing perspective. Finally, this perspective is effectively blind to the instrumental (e.g., physical) aspects of task performance, leading to a corresponding blindness to the "mechanics" of collaborative activity.

In summary, the information processing perspective is derived from a science of humans, where humans are considered individually and only as symbol processors. We are not refuting the utility of this perspective; we are only noting its limitations for our stated purposes. Most important for research methodology is the fact that an information processing perspective is limited in addressing either individual or team task performance, because it fails to adequately link general behavioral characteristics with salient details of the work domain and task. The gains derived from a scientific analysis of human capabilities are offset by a loss of connectivity to the work domain semantics that significantly influence work practices. This is well demonstrated by the empirical work of Klein and others refuting the notion of skilled performance as rational / symbolic

processing in support of decision making (e.g., Klein, 1989; Klein *et al.*, 1986; Klein *et al.*, 1993). The information-processing framework is not "large enough" to offer an adequate scientific foundation for principles of interface design. While this approach has proven useful, it does not constitute what we believe to be the optimal theoretical stance for our purposes -- a system science concentrating on the interaction of human with machine in the course of doing work.

2. The limitations of interface research's focus on the individual

The second such factor relates to the mode of conventional IT deployment in work settings -- each user employing a desktop workstation to accomplish his / her individual tasks and / or (via LAN or WAN connections) those tasks in which he / she must collaborate electronically with other team members. There should be little surprise at the fact this has biased the relevant research toward what the individual team member confronts at his / her personal zone of contact with IT support (as opposed to what the team as a whole must confront with respect to its overall IT support infrastructure). As a result, experimental work on human-computer interaction (HCI) has undervalued both team (as opposed to individual) performance and the task context within which that performance is realized (Bannon, 1991).

As a result, little or no tangible progress has been made with regard to mechanisms, protocols, and representations explicitly geared to support team performance. The extent of results in this direction is typified by Hewitt and Gilbert's (1993) general observation that interfaces for team IT usage must contend with three factors beyond those addressed for individuals' workstation interfaces: a) communication among team members; b) managing inputs from multiple users; and c) social interactivity among team members. Furthermore, what little consideration has been given team IT support can be characterized as focusing outside the scope of our concern. For example, Malone (1985) outlined a need to address "organizational interfaces", defined as "the parts of a computer system that connect human users to each other and to the capabilities provided by computers." (1985, p. 66) This definition would seem to be relevant to our concerns, but the fact is that Malone's elaboration of the concept remained anchored at an organizational (i.e., enterprise-wide) scope. As such, Malone's models for such interfaces were framed at a level of generality too broad to constructively inform us on specific teams' IT requirements.

B. A Theory-Based Approach to Interface Design Principles

What is needed is a method to derive interface design principles that combines knowledge about human capabilities with knowledge about connections to both individual and team work processes as they are operant in an actual work domain. This presents a substantial challenge, since the aim of science is to produce explanations for fundamental phenomena. Such phenomena extend beyond the limits of the idiosyncrasies

7

of any specific task situation or work domain. Since work processes in a domain involve local details of the domain, how then can we establish a scientific basis for design principles if work processes are important to interface design? Our solution to this problem is to appeal to and extend the construct of expertise. Humans who are considered to be good at solving problems are said to be experts. In other words, they have the property of expertise, either God given or acquired. As used here, expertise is taken to be the outcome of a skilled acquisition process. Importantly, it depends on experience in a work domain. Now, if we take a process view of expertise, there is evidence to suggest that the processes used by experts apply across domains. This is true even though specific domain content serves to trigger process actions.
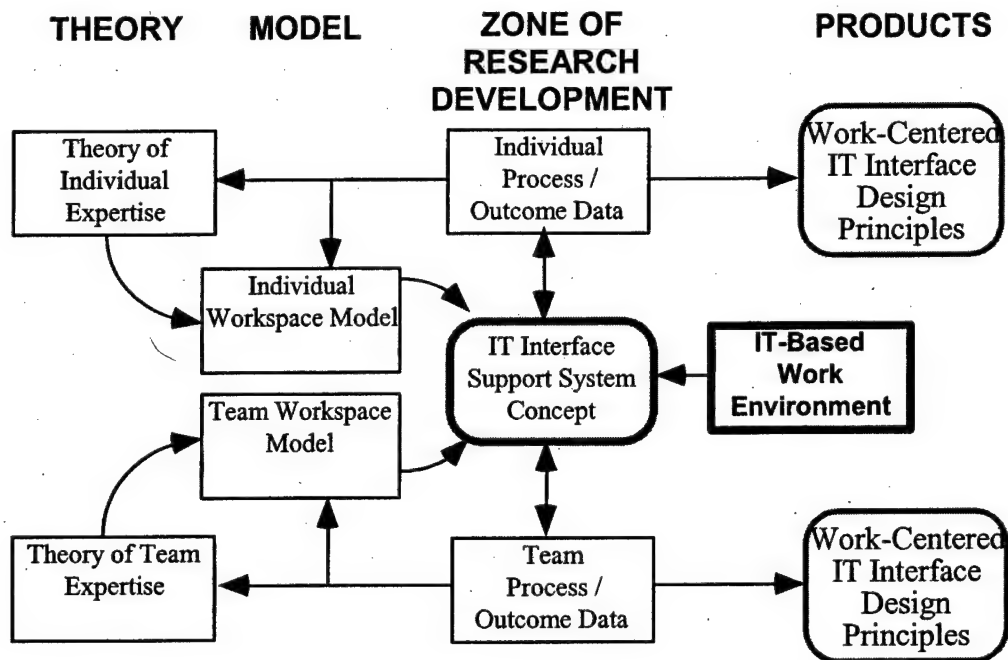
Figure II.1: The CSTL Theory-Based Approach to Work-Centered Interface Development

A process model of expertise can be used to establish principles for interface design based on the assertion that the interface should strive to support expert process behavior. A process model of expertise is general. It applies to all experts and, therefore; it is amenable to scientific study and can provide a foundation for development of interface design principles. Effective interface design, however, also depends on knowing the "triggers" embedded in actual domain situations that must be incorporated into the work process if the user interface to a work system is to be effective. Therefore expertise theory, expressed as a model, must be supplemented with a work domain model that captures such triggers before the theory can support predictions of performance in a specific work domain. It is in this way that local domain semantics and global work syntactics are combined in the scientific study of expertise. It is for this reason that a theory of expertise is the cornerstone to a scientific approach to forming interface design principles that are sensitive to domain specific factors.

8

Figure II.1 is a flow diagram of our theory-based approach to produce work-centered interface design principles applicable to IT. Twin process models of expertise (one each for individuals and teams) capture or leverage the related theories of individual and team expertise. Both are needed since an interface must support individual work at the same time it supports teamwork. The theories are expanded into workspace models that characterize the activity space in terms of a set of abstract constructs. These models are "open" in the sense that they support many process trajectories through the activity space. A more detailed discussion of theories of expertise and the workspace model is presented later in Sections E and F. Actor perceptions and events within a work domain (IT-Based Work Environment) trigger both situation understanding and process activities. Interface concepts derived from analyses of these processes, perceptions, and events will support teamwork and individual taskwork. These theory-based concepts are tested empirically through the use of simulated work environments that have characteristics of real-world military task situations. Importantly, both process data and outcome data analyses are performed to assess predictions.

This model was explicitly crafted to allow for CSTL learning (in the sense of evolving the tools employed) as well as the export of practical research products. Results of the investigations are applied to improve the theory and workspace models and to produce a stream of interface design principles and information requirements for IT systems. As implied by the feedback loops, the development iteratively modifies both theories and models as necessary until a mature state is reached.

C. Emerging Model of the User Interface for Highly Connected Work Environments

It is common to regard the user interface as an information channel connecting a human with a machine, or connecting sets of humans through a machine or medium. Advances in software technology suggest that an information channel view is no longer adequate as the basis for the design of user-system interfaces. The notion of an interface continues to need redefinition. What is a team interface? Do we gain any design leverage by using such a concept? What is the interface to emerging IT? We have addressed the basic question (What is an interface?) elsewhere (Eggleston, 1988). For this research project, it is important to have a clear understanding of the user interface in an IT environment. We suggest that IT may profoundly change the workspace and thus we need to re-evaluate its functional purpose in a more highly connected, distributed work environment. The IT interface needs to be characterized both from a hardware/software perspective and from a functional/purposive perspective. This section provides an introduction to this topic.

As stated earlier, IT offers an unprecedented level of connectivity of people, information, tools, and imagery. It is a medium for work and for exchange. This implies that functionally the interface is more than an information channel. It is also a richly textured work place for people working alone and in teams. To understand the interface

capabilities and limitations from a hardware/software perspective, we have developed the following interface model. A more detailed discussion of the model is provided later when describing infrastructure development for this project taking place in the Collaborative Systems Technology Laboratory (CSTL).
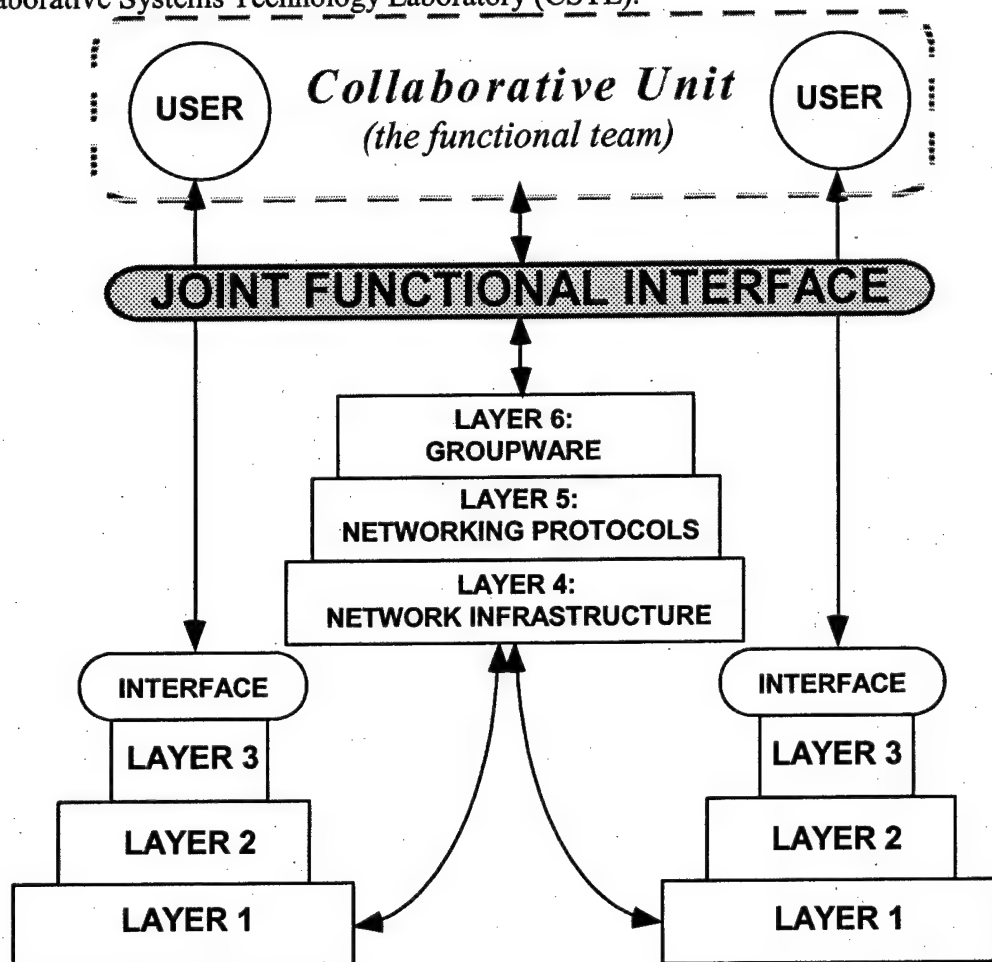
Figure II.2: General CSTL Model of a Networked Collaborative System

IT provides a core technology for the development of highly connected, collaborative work environments. Figure II.2 presents our model view of a networked collaborative system. This depiction emphasizes the IT infrastructure and shows a progression from specific hardware (the lowest "layer") to the software applications supporting collaborative tasks in network environments ("groupware"). The vertical ordering of these layers is not intended to connote some strict hierarchical segregation. Instead, it lays out the relative dependency of elements required to build up and exploit networked information technologies. The lowermost three layers comprise the collection of elements required to realize a single-user workstation (hardware, operating system, and application software). Individual users engage this subset of the network topology in any case, and the "interface" elements shown represent the conventional usage of the term. The upper three layers represent the collection of elements required to "enhance" an individual workstation to interoperate with others via a network.

Figure II.2 also shows the collection of interfaces in this highly connected work environment. Participants in collaborative work effectively engage the technology and each other through three distinguishable interfaces. The first (denoted "interface" in Figure II.2) is the conventional zone of interaction between the individual user and his / her workstation. The second (which we term the *joint functional interface*) denotes those work support mechanisms through which collaborators or team members a) engage the objects of their joint effort and b) engage each other to (e.g.) exchange and clarify "messages" to facilitate coordination, synchronization, or specific aspects of individual or joint task work.

The reason for distinguishing between these types of interfaces is that analysis of joint network operations requires some means for disentangling the confusing overlap and interdependencies among each operator's access to and interaction with their immediate toolset (workstation), their joint/virtual product (shared information artifacts), and each other. This preliminary model view accomplishes this end. Moreover, it helps to clarify what is missing from current IT developments which are of greatest importance to the development of new organizational processes and team performance within them. Specifically, little or no attention has been devoted to identifying or developing a joint functional interface. The model raises this issue as a central concern.

D. Team Performance

The purpose of the joint functional interface is to facilitate effective team performance. To insure sound investigation of the relation of mechanisms of such an interface with team performance, we need a framework that can be used to make meaningful distinctions among types of teams and the locus of work being moderated by the IT interfaces. Investigators who have been researching different aspects of team behavior have developed various taxonomies and theoretical models to account for their findings. Recently, Regian and Elliott (1997) have advanced an interesting framework for quantitatively modeling the effectiveness of team performance. Their framework consists of a clear definition of teamwork (at the functional purpose level), a taxonomy that can be used to establish team types in accordance with the teamwork definition, and a six-factor model of team effectiveness. It is a comprehensive framework for guiding team performance research. It is summarized here to show where in this broad framework our research fits in, as well as how our approach differs, in part due to the concern for the interaction of teamwork with IT.

Based on a more or less standard view of teams, as distinct from groups, Regian and Elliott derive a functional definition of teamwork: "...team work is the effective managing of interdependencies to accomplish team goals." Clearly, this definition assumes that active team goals are understood and recognized by all team members.

11

Given this assumption, then it is reasonable to differentiate teamwork types based on the nature and extend of interdependencies.

Regain and Elliott develop a taxonomy to help explicitly differentiate teamwork types in terms of interdependencies. Their taxonomy is derived from the relationship between an individual work or task complexity dimension and a stage model of human work. The stage model is expressed in terms of four cyclic stages [Information (acquisition), Deliberation, Resolution, and Action], and the task complexity dimension is partitioned into 4 regions. This results in a 4 by 4 matrix where cell descriptors suggest the degree of dependencies that may be involved to achieve the work at a stage according to its complexity. The most complex situation consists of information that is fuzzy (ambiguous, uncertain); deliberation is mental model based and involves fuzzy, complex, contingent procedures; resolution requires expert judgment; and action requires expert level performance. At the simple end of the scale, information is concrete in form; deliberation involves only facts; resolution can be obtained with simple rules; and action is only dependent on basic abilities.

The final element of the Regian and Elliott framework is a six-factor model of teamwork effectiveness. The factors are: allocate tasks, allocate resources, exchange information, determine strategy, monitor team performance, and adaptive problem solving. It is easy to see how the first four factors relate to team interdependencies. Team performance monitoring is clearly a meta-level factor. As a factor, adaptive problem solving may be a composite of the first four factors. However, it is not clear how Regian and Elliott intend to handle the dynamic characteristic of this factor.

This framework has been established to support theory-based development aimed at formulating training intervention strategies, methods, and techniques to be used to facilitate teamwork for different types of teams and work situations. It appears to be nicely developed and well suited to this purpose. Our research objectives are also concerned with the effectiveness of team performance, but the focus is slightly different. Just as training methods can contribute to good team performance, so to can the content, form, and behavior of the interfaces among team members and information network technology, including embedded tools. Our objective is to understand this interfacing relationship to the point where theory-based design principles can be established to guide interface development. Ideally, we would like to be able to make performance predictions about how well interfaces developed from such principles impact team effectiveness.

Similar to Regian and Elliott, we approach the problem from a skills perspective. Based on our assessment of the emerging digital battlefield and concepts of operations, we believe that the user interface with network IT must be able to support expert-level teamwork. Thus, the types of teams we are most interested in have the interdependencies suggested by the high-end column in the Regian and Elliot taxonomy. Accordingly, we hypothesize that the effective functional purpose for the joint functional interface of a network IT system is: **to serve as a support system to facilitate expert-level individual**

and team problem solving performance. Thus, this serves as a definition of a collaborative interface. The interface is a support system, not merely an information/communication channel. (although that will clearly be one aspect of its support function). More specifically, it is a support system for expert problem solving behavior. This, of course, begs the question, what is expert individual and team problem solving behavior?

E. Characterizations of Expertise

1. Individual expertise

Expertise has been characterized as know how (i.e., the ability to establish an effective problem characterization and adaptively execute it with real-time modifications), versus simply knowing that (i.e. knowing facts, rules, and procedures). All skilled behavior may be regarded as dependent on basic abilities, training, and experience. Experience, often substantial in amount, is generally regarded as essential to the formation of expert-level skill. In this sense, it is a defining property of expertise. It applies for expertise at each stage in a work model or for the entire constellation of activities that defines work. Further, it suggests that to understand expert behavior, one must observe experience workers in their work situation. Retrospective reports and other approaches are not likely to be satisfactory because much expert behavior is automatized and it is characterized below the awareness level of the performer.

Over the past several years, Klein and his associates have been studying expert decision making in complex, high dimensional tasks, such as fire fighting, neonatal intensive care, electric power control, and various levels of military command activities (e.g., Klein, 1989; Klein *et al.*, 1986; Klein *et al.*, 1993). By employing various observational and cognitive analysis techniques, these researchers have succeeded in building a large base of empirical data on decision processes "in the wild" and distilling sound inferences from this base. Based on their findings they have advanced a recognition-primed model of decision making in naturalistic settings to characterize expert decision making behavior in the ill-structured task situations upon which they've focused. Klein's overall characterization of the perspective emerging from this research is conventionally labeled *naturalistic decision making (NDM)*.

The more formal or abstract aspect of this work is Klein's *Recognition-Primed Decision (RPD)* model of decision making, which we shall exploit in developing our workspace model for expert-level task behavior. Within the framework of the RPD model, Klein (1997) develops a list of functional behaviors in which experts engage and identifies methods or strategies they use to accomplish them. These key functional activities: (1) noticing patterns, (2) seeking information, (3) meaning making, and (4) managing uncertainties.

As Klein and others have noted, expert performers often do not view themselves as making decisions; rather they simply notice patterns that are meaningful based on experience. This is the essence of the RPD model. When the recognized pattern needs elaboration or verification, experts seek additional information, being guided by the initial recognition. Part of the verification or elaboration process may involve the construction of a story to "see" if the emerging situational understanding makes sense. This meaning making activity may also involve prediction, extrapolation, and the use of meta-cognitive reflection.

Ambiguities and uncertainties typically abound in ill-structured real-world environments. The final activity required of an expert, then, is to manage these uncertainties. Klein views such management in terms of (1) knowing when to accept uncertainty and press ahead, (2) knowing when to seek more information to eliminate uncertainties, and (3) knowing how to look differently at the situation such that the critical uncertainties simply vanish. This characterization may be regarded, at least loosely, as a descriptive work process model of individual expertise. It represents a description of the general properties of expertise that are made manifest in each specific work context. The details of each activity will be different for each job episode. Because this general character of the work process is evidenced in all the contexts studied by Klein and his colleagues, it is reasonable to consider them general characteristics of expert behavior. Further support for this position comes from Dreyfus's account of skill acquisition. Dreyfus and Dreyfus (1986) present a five-stage model of skill acquisition that includes expert behavior as the highest level of skill. They identify many of the same characteristics of expert behavior as theses suggested by Klein. Similar observations were made by Chase (1986) and Chase & Simon (1987) in their studies of chess masters.

2. Team Expertise

It is generally accepted that the phenomenon of (individual) expertise exists and thus is a valid subject for scientific investigation. This is true even though many may also believe the construct remains to be adequately parametrized. The concept is appealing because it seems to make contact with a quality of behavior observed in real life that is not captured by a more analytic or rational characterizations of decision making and other highly skilled activities. In the same spirit, it may be useful to extend the notion to a team as an entity. What do we mean by team expertise?

As Regian and Elliott point out, individuals exhibit behavior, not teams, and thus in some sense a team cannot be said to have expertise. But in another sense, expertise can be viewed as a team property based on coordination and synchronization of activities (i.e. interdependencies). Thordsen, Klein, and Kyne (1994) have viewed teams as cognitive entities and used observational strategies to investigate team decision making. Based on this work they have advanced a model of team decision making that may be regarded as a description of properties that define team expertise. Their model is called the Advanced Team Decision Making (ATDM) model. It consists of four constructs that summarize a set of 13 behaviors believed to be essential to high performance (expert) teams. The constructs are: (1) Team Competencies, (2) Team Identity, (3) Team Cognition, and (4) Team Metacognition. Team competencies refer to both individual team member skills and to proficiency in common coordinated action routines. As the name implies, Team Identity indexes the degree to which individual members feel connected to the team. Team Cognition focuses most directly on joint or team problem solving, decision making, and/or action taking. Behavior markers such as having a common goal, having a common picture of the problem situation, recognizing when their course of action is on-track, off-track, falling behind, etc, identify it. Team Metacognition refers to behavior aimed at team operations themselves, such as noticing emerging problems and taking responsibility to head them off, correcting problems, and helping out when a team member seems to be falling behind.

We believe that a characterization of individual and team performance (problem solving, decision making, action taking) in terms of the expertise construct provides a good point of departure for studying the interaction between team interfaces in highly connected network-based work environment and team effectiveness. A more traditional approach would view team behavior from a rational choice perspective, and assert that team members would systematically search for relevant information, systematically manage coordination and synchronization, and methodically weigh identified alternatives in the process of identifying and taking a course of action. Observations of high achieving performers in demanding real-world situations suggest that a rational choice framework is not consistent with their behaviors. Rather, the expertise view, although perhaps less precise and not as thoroughly developed, better reflects actual work process behavior. Given our stated hypothesis that the joint functional interface for an IT-based work environment should be designed as a system to support adaptive team problem solving,

one approach to establishing design requirements for the interface is to model support around what is needed to facilitate expert behavior.

F. Workspace Models

Expert behavior is adaptive and partially self-organizing. Any system that has this characteristic may be said to be "open" in the sense that multiple degrees of freedom for action taking remain available until the (human) system itself decides to close them. This implies that whether or not a closed-loop approach is employed to model the cognition of the human, such an approach (in which only discrete trajectories can be modeled) is insufficient for modeling task activities themselves. A closed-loop model requires that all degrees of freedom be eliminated except for those that support specific trajectories. Since there often may be a very large, possibly infinite, number of trajectories available to human actors in a given context, closed loop models are usually developed for only a small set of characteristic trajectories. For ill-structured, complex situations, observational studies indicate that garden path trajectories are rarely followed. Thus, the utility of a closed-loop model is compromised in multi-factored, ill-structured situations. A different modeling approach is needed to adequately explore expert individual and team performance in these situations.

We have elected to follow a modeling approach which focuses attention on the collaborative scenario as a *workspace*. This approach attempts to describe the boundaries that specify the region of work (i.e., the "workspace") within which the expert develops a course of action. Rasmussen *et al.* (1994) and Flach (1996) have characterized a workspace in terms of so-called constraint boundaries. These boundaries may be delineated with respect to a number of referential or indexical parameters. For example, Rasmussen has used high level abstract constructs such as workload to demarcate the type of workspace analyzed in his cognitive systems engineering work (Rasmussen *et al.*, 1994). Flach and Warren (1995) employ competing goal constraints for low-level flight and safety to generate a cohesive depiction of a workspace for safe flight. They define a workspace in terms of these intentional constraints coupled with physical constraints deriving from environmental, structural, and avionic factors. To date, such workspace description has proven useful for specific tasks or scenarios.

However, no attempt has been made to capture a general view of work processes in a single workspace model. We propose to express a theory of expert performance in terms of a work activity model represented as a workspace. Our approach takes Klein's RPD model of individual expertise as a point of departure and develops the workspace description in a different manner.

The results of initial model development are presented in Figures II.3 and II.4, which illustrate our approach with respect to individual and team expert-level performance, respectively. The two models have essentially identical layouts in which a set of tree

16

structures (the left-to-right horizontal extensions) are related to each of the four key functional behaviors identified by Klein (and listed vertically). Each tree originates with one of Klein's key behaviors and progresses toward an executable procedure. Intermediate branches in the tree identify such things as object of focus and relative environmental uncertainty in the problem space. In toto, the tree set captures a space of possibilities cast from the perspective of expertise patterns discernible in the best available empirical data.

Experts freely navigate through this tree set. No course is prescribed. However, the relative environment state variable (i.e., level of uncertainty) acts as a bias term and thus can serve as a pruning mechanism for shaping the workspace. Recall that managing uncertainties was one of the key factors in Klein's theory of individual expertise. We have not, however, listed uncertainty management as one of the four primary behavior classes. It is explicitly subsumed in the model within some of the intermediate branches of the Action Taking tree. This is a deliberate depictive arrangement. Because we are aiming to address performance (i.e., quality of action), we must make room for "action taking" as one of the main categories. Uncertainty management is not represented as a root for a primary tree structure because the work process requisite to this behavior is expected to include some combination of the four root work process activities listed. Phrased another way, we have treated uncertainty as a central, quantifiable control variable in our model, while integrating an explicit category of action taking which can subsume (e.g.) the end state of a simple linear trajectory through the Klein behaviors (i.e., moving from top to bottom in the figures) and / or those behaviors which may be recursively "spun off" in achieving some form of closure to the activity being modeled.

FOCUS: UNCERTAINTY: ACTION / PROCEDURE:

PATTERN RECOGNITION	Problem Framing	
	Course of Action	
INFORMATION SEEKING	Problem Framing	
	Course of Action	
MEANING MAKING	Problem Framing	
	Course of Action	
ACTION TAKING	Action Toward Understanding — HIGH	By Priority / Best Practice (B.P.)
	Action Toward Understanding — LOW	Execute: Plan / Execute: Priority / B.P.
	Action Out of Understanding — HIGH	Probe-Test-Commit
	Action Out of Understanding — LOW	Execute: Plan

Figure II.3: Workspace Model for Individual Expert Behavior

A similar tree structure is used to represent the workspace devoted to team activities by expert team members (see Figure II.4). This workspace is identical in form to that for individual problem work. The only difference is in the focus of the work problem. The assumption is that basic expert work processes apply at the team level as well as at the individual level, but with the indicated change in foci.

In some sense these models compile the work process theories of expertise. They leave open the trajectories an expert may take. Thus, they do not provide a basis for predicting specific performance outcomes. But they are helpful in other ways and they suggest other types of testable hypotheses. For example, the model suggests that experts will tend to use "best practices" when they do not have more insight into the problem situation. This means that we need to be able to tease apart best practices from other bases for activities when analyzing process data. In its current form, the workspace model predicts that under low environment state uncertainty experts will tend to commit to an action process that contains embedded tests to insure correct understanding of environment state. When

18

environment state uncertainty is very low or zero, then deliberate testing will tend to be replaced by no testing or only incidental testing that occurs as a by-product of goal directed activities. Under high environment state uncertainty, the activity pattern will tend to change to a more cautious probe-test-commit sequence. Process data can be used to identify these patterns.

Figure II.4: Workspace Model for Team Expert Behavior
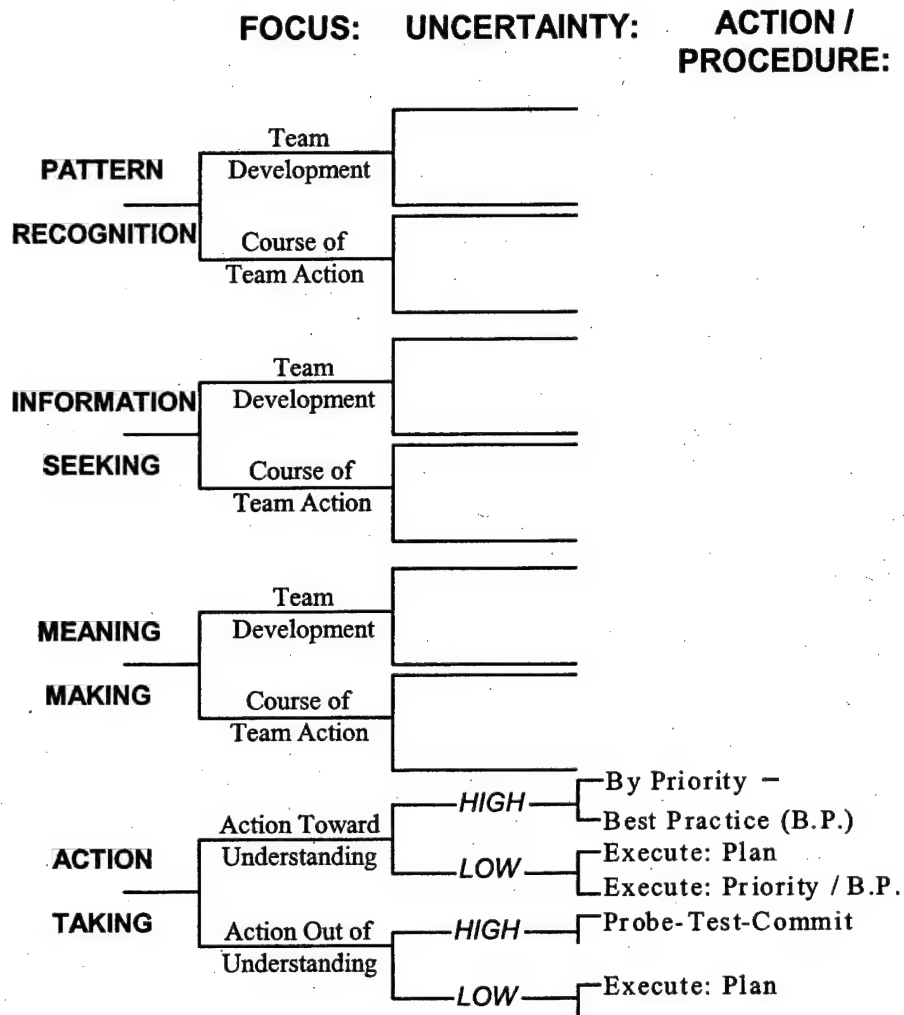
The framework provided by the theories of expertise and the workspace models provide vital guidance for what activities the joint functional IT interface needs to support. It does not suggest specific forms of interface mechanization since they will change based on the capabilities and limitations of the specific IT platform(s) implementing a given work support system.

G. Summary

Section II has presented a progressive explanation of the background to CSTL's conceptual or theoretical "infrastructure." As has been demonstrated, the key construct of "interface" is central to framing our research goals. We have presented detailed reasons for questioning the problematically individualistic focus of interface research and development to date, and we have linked this to the prevailing information processing paradigm and the mode of IT deployment upon which such work has concentrated. We have recontextualized interface issues in terms of more concrete, more quantifiable, and hence more "scientific" constructs (performance, expertise, and workspace). These alternative focal constructs have been introduced in a progressive fashion, tracing a logical path along which at each "waypoint" we have applied knowledge of the current state of the art to critically analyze our central topic (interfaces). Similarly, at each such point we have introduced a product in the form of a model or framework which "leverages" our interest in interfaces with respect to the given issue or phenomenon. In Section III we shall turn our attention to CSTL's IT infrastructure development and its application to demonstrate interface issues and problems in the context of a simulated distributed BMC4I exercise.

III.
PROJECT DEVELOPMENT:
PHYSICAL INFRASTRUCTURE ACTIVITIES

This project was initiated in March 1997. During this reporting period we have developed a framework for investigating interactions between team performance and the user interface with the IT network systems, as described earlier. The complete framework includes a conceptual description of a user interface in a highly connected IT-based work environment, along with work process theories of team and individual expertise and associated workspace models. In addition, we have also completed the first phase in the development of an IT network infrastructure that can be used to support empirical testing of team performance in an IT-based work place. A detailed description of this work is presented in this section.

The Collaborative Systems Technology Laboratory (CSTL), Fitts Human Engineering Division (AL/CFH), Armstrong Laboratory, Wright-Patterson AFB OH, is the newest laboratory unit within the division's Collaborative Systems Technology branch (CFHI). One of this laboratory's missions is to explore those human performance issues surrounding the utilization of advanced information technology (IT) in support of distributed joint operations. This document describes both the context for and conduct of an active demonstration (hereafter called the "BMC4I demo") developed to:

- Instantiate and test initial CSTL conceptual models relevant to analysis of collaborative systems
- Test simulation applications of the initial CSTL technological infrastructure (e.g., networked computers and collaborative software)
- Demonstrate CSTL's ability to simulate key elements of operational work domains
- Spotlight problematical issues surrounding the application of networked / distributed information technology in support of joint operations' BMC4I
- Evaluate any constraints or limitations in readily-available COTS software designed to support multi-user collaboration (i.e., "groupware")

At the time of the initial BMC4I demo exhibition, only approximately 50% of CSTL's initial equipment inventory had been received and set up. As a result, the BMC4I demo had to be outlined, planned, and executed using only those hardware and software resources already in place. The effects of this situation are discussed more fully in the *Technical Background* and *Limitations and Constraints* sections below. In spite of the infrastructure restrictions, CSTL personnel succeeded in setting up and presenting a demonstration which illustrated problematical issues in joint force BMC4I operations and some features of the COTS technologies presently available to meet these challenges.

A. Programmatic Background

1. Background

a. Networked BMC4I as a "System of Systems"

CSTL's agenda is to explore the means by which warfighter engagement with complex information systems can be framed, analyzed, and constructively modified. *Battlespace management C4I* (BMC4I) concepts continue to evolve in response to post-Cold-War exigencies, technological innovations, and the U.S. military's increasing emphasis on joint force operations. One key focus in this evolutionary development is *information technology* (IT) and its role in future military missions. A force's IT infrastructure is now seen as an operational component subject to offensive and defensive manipulations, and "cyberspace" is now seen as a virtual landscape worthy of tactical and strategic concern. Broadly stated, these two perspectives comprise the still-coalescing area of *information warfare (IW)*.

The application of advanced IT in support of joint operations entails a technical infrastructure capable of providing personnel the tools needed to function as a coordinated whole even though they may be located throughout a theater of operations or all around the planet. The most basic such tools must afford participants mutual access to each other (i.e., communications) and uniform access to information and knowledge bases (i.e., information retrieval). Information technologies supporting these fundamental functions have been developed and deployed for decades. More recent innovations have now laid the foundation for further leveraging IT by allowing for dynamic interactions with data streams and information elements (as opposed to the relatively passive nature of information retrieval). In the civilian realm, this development parallels the evolution toward increasingly interactive Internet usage, as illustrated by the progression from FTP and Usenet toward the World Wide Web (WWW) and online multimedia.

One illustrative construct critical to emerging DOD concepts on employing networked IT is the *system of systems (SOS)*. This construct is strongly associated with Admiral William Owens, who popularized it as a means for describing the complex interplay of distinguishable systemic elements to realize an overall operational system. To given an example with respect to achieving battlespace *information dominance,* Owens (1995a; 1995b; 1995c), outlined three ensembles of systems contributing to an SOS architecture for theater operations -- *battlespace awareness, advanced C^4I,* and *precision force use.* The focus of the work reported herein is the central (C^4I) component of Owens' breakdown -- i.e., the system "...that converts the information derived from battlespace awareness into deeper knowledge and understanding of the battle space..." and in turn "...converts the understanding of the battlespace into missions and assignments designed to alter, control, and dominate that space." (Owens, 1995a, p. 38) As will be seen later, the BMC4I demo was crafted to concretely illustrate technical aspects of these processes of conversion.

b. CSTL's Focus: Interfaces within the BMC4I System of Systems

Given its human factors / cognitive engineering mission, CSTL must match its programmatic focus to those system of systems issues which involve the engagement of humans and technologies. Current DARPA IT initiatives address networked operations in terms of SOS architecture, as illustrated in Figure III.1. Nodes (N) represent computers / workstations. They are linked to each other via data networks whose "hubs" are routers (R). A given node may be considered an element of multiple distinguishable systems (composite networks), depending on which router(s) and other node(s) are considered participants. Two such overlapping systems (1 and 2) are delimited by the dotted lines in Figure III.1.
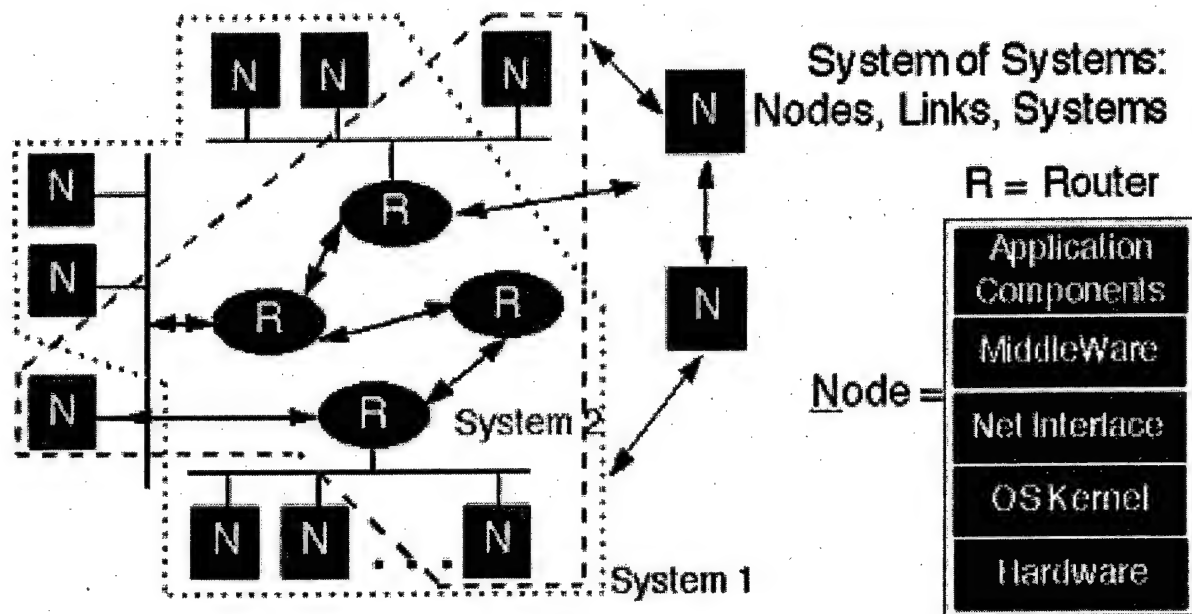
Figure III.1: DARPA's SOS Layout for Networked IT
Source: Shrobe (1996)

However, the illustrated DARPA application of the SOS concept addresses only the technological infrastructure. Because CSTL research must account for the human aspect of SOS operations, we must extend such an SOS analysis to more explicitly show the human-technology relationships. Online interactivity emphasizes and taxes the means by which users or operators engage complex information systems -- i.e., the *interfaces* through which they must work. The efficiency and effectiveness gains from interface innovations on individual workstations (e.g., windowing environments) are now being sought with respect to networked IT applications. However, such payoffs require a cogent research and development effort, and such cogency must entail a coherent notion of those "interfaces" which will serve as the focus of CSTL projects.

When addressing joint operations via IT networks, it quickly becomes apparent that the conventional notion of "interface" (the set of mechanisms mediating interactivity of an individual operator and a particular device or workstation) is insufficient. For one thing, network operations still require that actors engage their assigned workstations via such

conventional interface facilities. Phrased another way, "net-workers" use their individual interfaces to control their "windows" into a broader system so as to interact with others. The notion of the individual's interface is therefore still operant. The real concern is what additional concept(s) of "interface" must be introduced to span the range of issues surrounding human performance in distributed or networked missions.

Such conceptual innovation is difficult owing to the necessity of sorting out the complex interdependencies among individual and collective units of analysis (e.g., single users vs. teams; single computers vs. entire networks). For one thing, whole / part decomposition cannot neatly segregate the subject matter into discrete hierarchical layers or levels. Team performance is still contingent upon relative individual performance, and overall networked system performance is contingent upon specific subsystem performance (although in both cases the former is not strictly reducible to the latter).

Furthermore, any such "hierarchical" approach is confounded by the fact that networked task activities do not entail unique mappings of individual acts to one or another subset of the technological infrastructure. Any joint or mutual task accomplished via the overall network / system is pursued by individuals engaging their respective workstations. To give an example, people can engage in an online "chat room" discussion via their Web browser and desktop PC. It is reasonable to study the overall interaction among multiple such participants, but the nature and course of their interaction cannot be isolated from the fact that each one of them is wrestling with the particular affordances of the computer sitting before them. Conversely, it is reasonable to study the specific interactions between individual users and their PC's, but these actions cannot be isolated from the fact that they are collectively engaging in a shared conversational space.

2. The CSTL Conceptual Model for Addressing Collaborative Systems

In an attempt to account for these and other factors, CSTL has developed a preliminary conceptual model of human-system interfaces relevant to networked IT systems. The rationale for devising such a model is that:

1. The scope of critical information technology (IT) applications is evolving from an earlier focus on single-user / standalone implementations toward multi-user / networked implementations.
2. Given our division's human factors / cognitive engineering mission, our focal concern would be the interface(s) via which humans interact with their respective workstations and (via their respective workstations) with collaborators in the context of a joint operation.
3. Models and other analytical devices addressing the single-user / standalone implementation modality do not leverage issues delineated with respect to interactions among multiple actors and/or multiple workstations.
4. Models and other analytical devices addressing IT-supported collaboration do not leverage issues pertaining to the individual's interaction with his / her workstation.

As a result, the pursuit of CSTL's mission required that we first attempt to identify and delimit the relationships between individual and collective "foci" on information technology -- particularly as they pertain to human-computer interfaces. Conventionally, the term "interface" has been applied to a scenario of one user to one artifact, as in the case of desktop computers. Upon closer examination, one realizes that the user interacts with multiple distinguishable subunits of the composite hardware / software suite which a typical PC represents. We speak of the "interface" to a specific application software package (e.g., Microsoft Word), the "interface" to the operating system (e.g., the Macintosh), and the "interface" to the hardware itself (e.g., keyboard and mouse). Insofar as the user engages these distinct elements as one suite of mechanisms, it does little harm to colloquially consider this suite as a unary whole (i.e., "the interface"). For the purposes of scientific analysis and experimentation, it is necessary to impose a stricter accounting. Such an accounting underlies the CSTL conceptual model for an individual interface illustrated in Figure III.2.
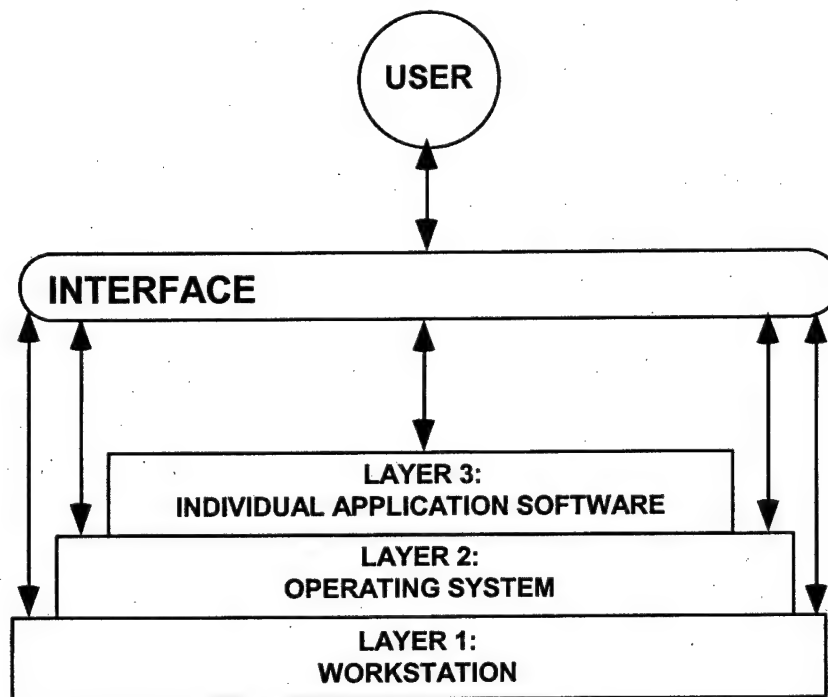
Figure III.2: CSTL Conceptual Model for the Individual Workstation Interface

Figure III.2 covers the differentiable aspects of the "interface" between an individual user and his / her computer workstation. The 3-layer description of the workstation is a simplified variant of the 5-layer DARPA node architecture outlined in Figure III.1. To address multiple such user / computer dyads participating in a larger context (as in networked BMC4I), it becomes necessary to specify how the elements of the individual case relate to the collective case. The preliminary CSTL model accomplishing this expanded scope is illustrated in Figure III.3.

Figure III.3 depicts a progression from specific hardware (the lowest "layer") to the software applications supporting collaborative tasks in networked environments ("groupware"). The vertical ordering of these layers is not intended to connote some strict hierarchical segregation. Instead, it lays out the relative dependency of elements required to build up and exploit networked information technologies. The lowermost 3 layers comprise the collection of elements required to realize a single-user workstation (hardware, operating system, and application software). Individual users engage this subset of the network topology in any case, and the "interface" elements shown represent the conventional usage of the term. The uppermost 3 layers represent the collection of elements required to "enhance" an individual workstation to interoperate with others via a network. It is this additional set of elements which users utilize in collaborative interactivity.
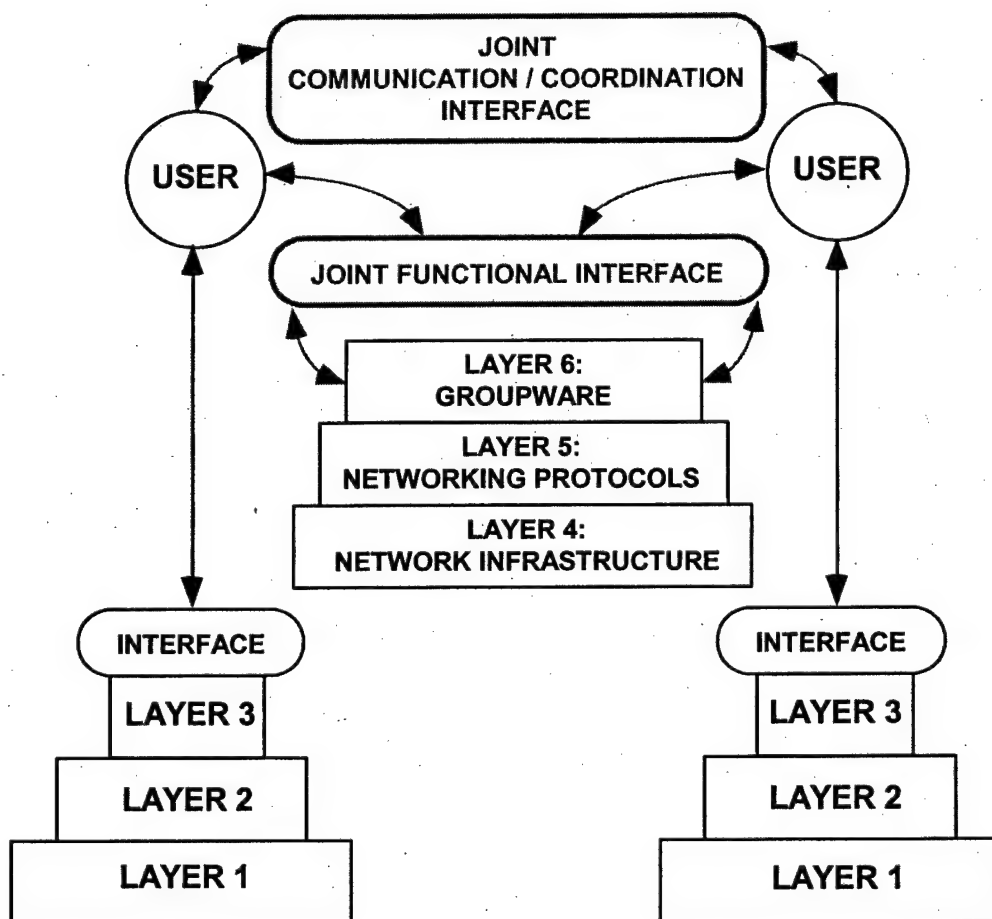
Figure III.3: The CSTL Model of Networked Collaborative Systems

With respect to the CSTL agenda, the model in Figure III.3 is an orderly layout of the various aspects of "interface" as they pertain to networked collaborative systems. It

should be noted that Figure III.3 differs from the very similar Figure II.2 in making a distinction between two aspects of the joint functional interface. Participants in collaborative operations effectively engage the technology and each other through three distinguishable "interfaces". The first (denoted "interface" in Figure III.3) is the conventional interface between operator and workstation. The second ("joint instrumental interface") denotes those mechanisms through which collaborators engage the objects of their joint effort. The third ("joint communication / coordination interface") denotes those mechanisms through which collaborators engage each other to (e.g.) exchange and clarify messages.

The reason for distinguishing among these three types of "interface" is that analysis of joint networked operations requires some means for disentangling the confusing overlaps and interdependencies among each operator's access to and interaction with their immediate toolset (workstation), their joint / virtual product (shared information artifacts), and each other. The preliminary CSTL model accomplishes this end, and it will serve as the main explanatory device for introducing and discussing the BMC4I demonstration.

3. The CSTL Model versus the DARPA System of Systems Model

As was noted for Figure III.2, the layout of Figure III.3 is a variant of (rather than an exclusive alternative to) the DARPA system of systems layout in Figure III.1. The Network Infrastructure of Layer 4 subsumes some elements of the router and "net interface" elements of the DARPA breakdown. The Network Protocols of Layer 5 do not have an explicit analogue in the DARPA model to the extent they are operant for the routers. One could make a case that to the extent they are operant on individual workstations (nodes), they are subsumed within the "net interface" element within the DARPA node architecture.

The Groupware that comprises Layer 6 would be subsumed under the applications portion of the DARPA node architecture, because it connotes software which ultimately runs on an individual's workstation. Our rationale for distinguishing a separate Groupware component does not contradict the DARPA model. For the purely technological orientation evidenced in Figure III.1, the subsumption of group-oriented applications within the general class of applications is reasonable and accurate. In shifting to the human-oriented stance necessary for CSTL's mission, it is useful to make a logical discrimination between software supporting individual tasks and software supporting team operations, and this explains the distinction between our Layers 3 and 6.

This last point illuminates the key difference between the DARPA SOS model and the CSTL model. The former is framed with respect to the technology per se, and the latter is framed with respect to operational interdependencies vis a vis the human(s). Recognizing this contrast of perspectives (as opposed to a conflict in meaning) allows us to complete the comparison of the two models. The DARPA SOS model usefully illustrates that multiple permutations of nodes (linked via routers) comprise multiple distinct technological systems. To the extent that these distinguished systems are comprised of elements which are themselves interconnected (directly or indirectly), all nodes can be descriptively subsumed within some total "netspace", just as a number of distinguishable networks are descriptively lumped together as "the Internet." Such a totalizing subsumption can negate the utility of a purely technological perspective, because this "netspace" becomes in effect a featureless backdrop to the phenomenon of interest. Phrased another way, such a totalizing subsumption robs the construct "netspace" of any capacity for analytical "leverage" with respect to CSTL's purposes.

This explains why (for our purposes) we have constructed the CSTL model from a more functional or operational perspective. The interface between a specific user and a particular workstation is a precisely delineable combination of technologies. However, the technologies employed to realize what we have termed the Joint Instrumental Interface and the Joint Communication / Coordination Interface need not be identical "systems" as defined in Figure III.1. Collaborators might simultaneously share information or data (Joint Instrumental Interface) via one such "system" while communicating person-to-person (Joint Communication / Coordination Interface) via

28

another. Furthermore, these distinctions might be mirrored by distinctions between technological infrastructures, as when one shares data via computer network and conversation via telephone in getting remote technical support (e.g., from a software vendor). To usefully analyze human factors aspects of distributed operations CSTL must be able to discriminate among the "virtual" or "logical" networks collaborators utilize, whether or not these distinguishable interactional channels can be mapped directly or uniquely onto the sets of node interconnections emphasized in Figure III.1.

As such, we would claim that there are no substantive clashes between the DARPA SOS model and the CSTL model of Figure III.3. Both play on the concept of "system of systems." The DARPA model lays out its SOS architecture with exclusive regard to technical infrastructure, and the CSTL model does so with regard to operational interdependencies vis a vis the human user / operator. Phrased another way, moving "upward" through the DARPA model entails a progressive subsumption of technological subsystems, while a similar traversal of the CSTL model entails a progressive subsumption of joint human-machine subsystems.

In the following section, the BMC4I demo apparatus will be introduced and contextualized as an instantiation of the CSTL conceptual model of Figure III.3. Later, in Figure III.10, we will provide a complete accounting of the specific BMC4I demo apparatus with respect to this model.

B. Apparatus for the BMC4I Demo

This section will outline the hardware and software elements providing the foundation for the CSTL BMC4I demonstration. These elements will be related to the six layers of the preliminary CSTL model illustrated in Figure III.3.

1. Hardware

a. Workstations (Layer 1 in Figure III.3)

The initial CSTL laboratory infrastructure will feature six Intergraph TDZ-series graphics workstations (each with two large monitors) and five Silicon Graphics workstations. These stations will enable CSTL to emulate the heterogeneity of the wide-area networks employed in joint operations. Large group display of information from one or more of these stations will be done with two InFocus Digital Light Processing (DLP) projectors and one or more large projection screens. Each of the Intergraph stations will be equipped with Connectix QuickCam digital cameras to enable inter-station video conferencing.

b. Network Infrastructure (Layer 4 in Figure III.3)

These computers will be linked via a 100Base-T CSTL internal LAN. A 10/100Base-T switch will link the CSTL internal LAN to the AL/CFH LAN and external (e.g., Internet) networks

As illustrated in Figure III.4, the two Intergraph stations (and the DLP projector) were linked via the 100Base-T CSTL internal LAN. The video data streams from the QuickCams as well as all other data communications between these stations were handled over the internal LAN. A third Intergraph TDZ-410 served as the large-scale display driver, sharing one common data display with the two other Intergraph stations and pumping this image to the DLP projector.

Of the two primary software packages employed (cf. the Software section below), one (NetMeeting) operated exclusively between the Intergraph stations over the 100Base-T internal LAN. The other (PowerPoint) had to be accessed independently by each station from the (10Base-T) AL/CFH LAN. This extended access link to PowerPoint had to be mediated by the 10/100Base-T switch serving as the gateway between the CSTL and AL/CFH LANs.

c. Hardware Summary

At the time of the first BMC4I exhibition, CSTL was capable of employing four Intergraph workstations (with QuickCams), the internal LAN, the external LAN connections, and one of the DLP projectors. These elements comprised the infrastructure basis for the BMC4I demo. Three of the Intergraph stations and all the other available elements cited were utilized in the BMC4I demo. For the purposes of the BMC4I demo, these elements were configured as illustrated in Figure III.4.
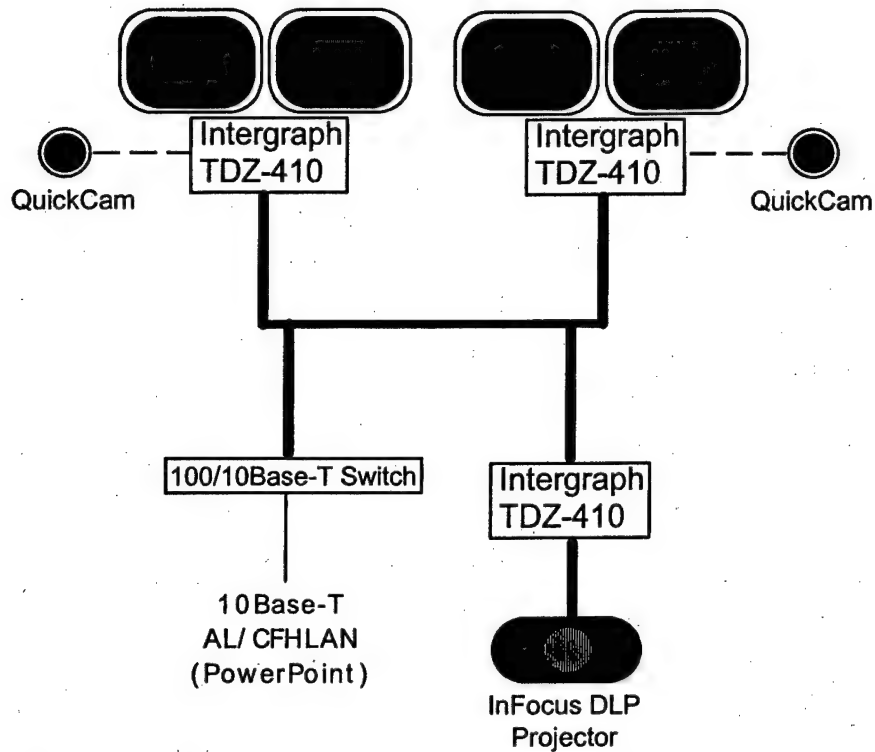
Figure III.4: CSTL Hardware Infrastructure for the BMC4I Demo

2. Software

a. Operating Systems (Layer 2 in Figure III.3)

All 3 Intergraph workstations were running Microsoft Windows NT 4. All software utilized in the BMC4I demonstration ran atop the Windows NT operating system. In the future, CSTL's heterogeneous internal LAN will provide the capacity for demonstrations, experiments, and studies more closely modeling the problematical diversity of wide-area networks.

b. Individual Application Software (Layer 3 in Figure III.3)

Most of the information displays presented at each station's monitor(s) were mocked up using Microsoft PowerPoint 4. Each individual "window" was actually a discrete PowerPoint file comprised of one or more slides containing the appropriate data. To set up the appearance of a coherent display, all the PowerPoint files were opened and their respective windows tiled on-screen to achieve the desired arrangement.

c. Networking Protocols (Layer 5 in Figure III.3)

The networking among the Intergraph workstations was accomplished using the TCP / IP protocol over the CSTL 100Base-T internal LAN. The networking required to access Microsoft PowerPoint from the AFRL/CFH LAN was accomplished atop the Novell NetWare IPX which serves as that network's resident "logic."

d. Groupware (Layer 6 in Figure III.3)

The shared collaborative whiteboard and desktop video conferencing functions were accomplished using Microsoft NetMeeting. This software, available free of charge from Microsoft, allows a combination of shared whiteboard, application sharing and two-way video conferencing on a point-to-point basis. The third Intergraph station (the one driving the projector) also employed NetMeeting's application sharing feature as a means for obtaining updated information fields (cf. the Information section below) to be presented on the large-scale projection surface.

The only windows presented at the stations' monitors which were not mocked up in PowerPoint were the two video windows and the shared whiteboard (which were presented via Microsoft NetMeeting). These windows were presented exactly as NetMeeting provided them (with some on-screen tiling and alignment to blend them in with the majority PowerPoint displays). A more detailed review of the BMC4I demo's information displays will be given below in Section V (Information Displayed, Shared, and Manipulated).

C. The BMC4I Demonstration Task Scenario

1. Overview

The BMC4I demo was constructed on the basis of a mock battlespace scenario. The scenario was generated for the purposes of the demonstration, and it does not reflect any specific past or planned circumstances. As illustrated in Figure III.6 (in section V.), blue forces deployed along the southern and eastern extremities of the Arabian Peninsula, as well as northward into southwestern Asia and southward in Somalia, were confronted by a red force westward. The red force was comprised of two primary groupings. The area of engagement with the northern grouping (centered in Syria) was designated "Alpha sector". The area of engagement with the southern grouping (centered in Sudan) was designated "Bravo sector".

The two workstations used in the demo supported the roles of one USAF operator ("Eagle Vantage Center") and one Army operator ("Fort Apache"). Each of the operators was assigned to monitor incoming event data from his/her respective portion of the battlespace (e.g., Army = ground; USAF = air). Based on this incoming data, and in coordination with the other player, each operator was tasked to compile summary information on the total (i.e., ground + air) situation in one of the sectors (Army = Alpha;

USAF = Bravo). This compiled information was to be posted to a sector situation summary which was then forwarded to a mock command center.

The three components of the BMC4I demo (USAF, Army, and CINC) were represented by three stations set up in the CSTL facility. The two operators were seated at Intergraph workstations side-by-side. This close proximity was judged reasonable for providing visitors a concise introduction and overview of the demonstration. An acoustics-dampening partition was inserted between the two stations, to reinforce the operators' need to communicate through the audio / video conferencing capabilities of the demo's groupware component (NetMeeting). The mock CINC station consisted of a large-screen projection of the Summary Situation Display and a conference table, located in another section of the CSTL facility. This arrangement is illustrated in Figure III.5.
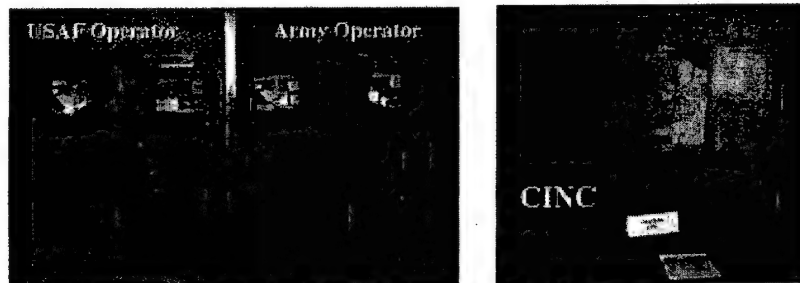
Figure III.5: Layout of the BMC4I Demo Stations

2. Issues to be illustrated by the BMC4I Demonstration

The demo's scenario layout was contrived to illustrate several issues which in one form or another had proven problematical in prior joint force operations. The following sections will briefly discuss these issues.

a. Distributed operations require attention to inter-operator coordination

The operators in the BMC4I demo were required to: (1) attend to incoming data for their designated battlespace focus (air vs. ground); (2) compile data from their respective incoming data streams; (3) exchange data with the other operator; (4) assemble a composite data product for their designated battlespace area (Alpha vs. Bravo sector); and (5) accrete this composite data product to the shared information space. Of these five basic functions, only the first two could be comprehensively accomplished by one operator in isolation. Functions (3) and (4) required transfer, comparison, and/or coordination of data items with the other operator. Function (5) required that the two operators take turns in accreting their respective data products to the shared information space. The coordination and turn-taking overhead required for functions (3)-(5) are typical for distributed or "groupware" software packages. Because this overhead is reflected by an additional cognitive / perceptual "load" on each individual operator, there

is an issue as to the extent to which positive collective performance effects are mitigated by negative effects of heightened individual workload.

b. "Vertical stovepipes" for data streams restrict lateral data sharing

The term "stovepipe" has been used for years to connote a data or information stream which is coherent and relatively impervious to inputs or outputs orthogonal to the primary direction(s) of flow. A "vertical" stovepipe is one where the primary directions of flow are "up" and "down" through a hierarchical organization (e.g., as illustrated by the classic chain of command). In the case of the BMC4I demonstration setup, there were two vertical stovepipes for data -- the USAF and Army data streams for air and ground events, respectively. Our basic demo layout afforded both operators access to both of these data streams, but this is not representative of the situation for many joint force operations. In all too many cases, operators from different services and/or working with distinct data streams have direct access to only their own (service's, mission's) data flow.

Where such "stovepiping" applies, lateral sharing of data / information (e.g., between USAF and Army; between air and ground components) becomes a major problem. Owing to historical differences in (e.g.) technical implementations, deployment styles, nomenclature, data formats, resource allocations, and procedures, joint force components up to and including entire services have found it anything but straightforward to communicate and collaborate among themselves.

c. "Stovepipes" can occur with respect to elements / factors other than data streams

The BMC4I demonstration illustrated a "stovepipe" of another type than the typical closed data stream discussed above. In addition to the restrictions deriving from the air- vs. -ground data distinctions, the two operators were specifically assigned to compile and export updated reports on subjects which were differentiated along yet another dimension -- Alpha vs. Bravo sector. Phrased another way, each operator had to contend with the limitations of an incoming stovepipe insulating air from ground data, in terms of collating data from his/her own and the other data stream. In addition to this problem, each operator was expected to compile a composite data product from his/her best synthesis of these two data streams and export it via what can be considered an outgoing stovepipe insulating Alpha sector from Bravo sector results.

Phrased another way, each of the BMC4I demo operators had to contend with "crossed stovepipes." With regard to incoming data, each operator had to concentrate attention and effort with respect to the air vs. ground distinctions governing battlespace component categorization and data stream allocations. With regard to compiling an informational product (updates to the Summary Situation Display), each operator had to concentrate attention and effort with respect to the Alpha vs. Bravo distinction governing battlespace territorial categorization and joint force allocations. This "switching" necessarily entailed doing one task from two distinct perspectives, so to speak. From a human factors

viewpoint, this would lead to a prediction of increased cognitive workload for each operator.

d. Mismatched resource allocations among data stovepipes and other restrictions further complicate operations

As noted above, each operator had to deal with two distinct types of "stovepiping" -- air- vs. -ground on the incoming data and Alpha-vs. -Bravo on the outgoing results. Neither operator could accomplish his/her task without taking the time to (a) distinguish which data coming from his/her own incoming stovepipe was relevant to the restrictions of his/her outgoing stovepipe and (b) determine the applicability of data from the other's incoming stovepipe to his/her own outgoing stovepipe. In effect, the operators were caught in a procedural crossfire induced by the figurative "crossing" or intersection of two distinct stovepipes at their respective stations.

e. The affordances of groupware applications induce restrictions on the collaborators' ability to work.

In the case of the BMC4I demo, the groupware (layer 6 in Figure III.3) was limited to Microsoft NetMeeting. It was through this software that the USAF and Army operators communicated (via audio / video conferencing) and jointly assembled their Sector Summary Display information (via the shared whiteboard). As with any groupware application, the affordances of NetMeeting affected the manner and efficiency of the operators' collaboration. A more detailed discussion of these effects (in the general context of COTS groupware) will be given in Section VI (Groupware Issues Illustrated in the BMC4I Demonstration).

D. Information Displayed, Shared, and Manipulated

Each of the two Intergraph operation stations was equipped with dual 21" monitors. For the purposes of the demo, we developed a structured screen display for each monitor. On the left-hand monitor was a mock-up of a summary situation display. On the right-hand monitor was a mock-up of an individual operator data display. These basic displays are illustrated below in Figures 6 and 8, respectively. In the following sections, each of these displays will be introduced and its component subdisplays explained. The subdisplay / display composition for each mock-up is explained in Figures 7 and 9, respectively.

1. The Summary Situation Display (Left - Hand Monitor)

The Summary Situation Display represents the shared information space linking each of the two station operators and their command center. The largest element of this screen display was the Summary Battlespace Display -- a "God's Eye" view of the geographical context for the simulated operations. Included in the Summary Battlespace Display were

symbolic depictions of adversary (red) and own (blue) forces, phase lines (planned deployment boundaries), combat air patrol (CAP) circuits, threat zones (areas of adversary SAM coverage), command posts, as well as individual / grouped platforms (specifically armor and air).
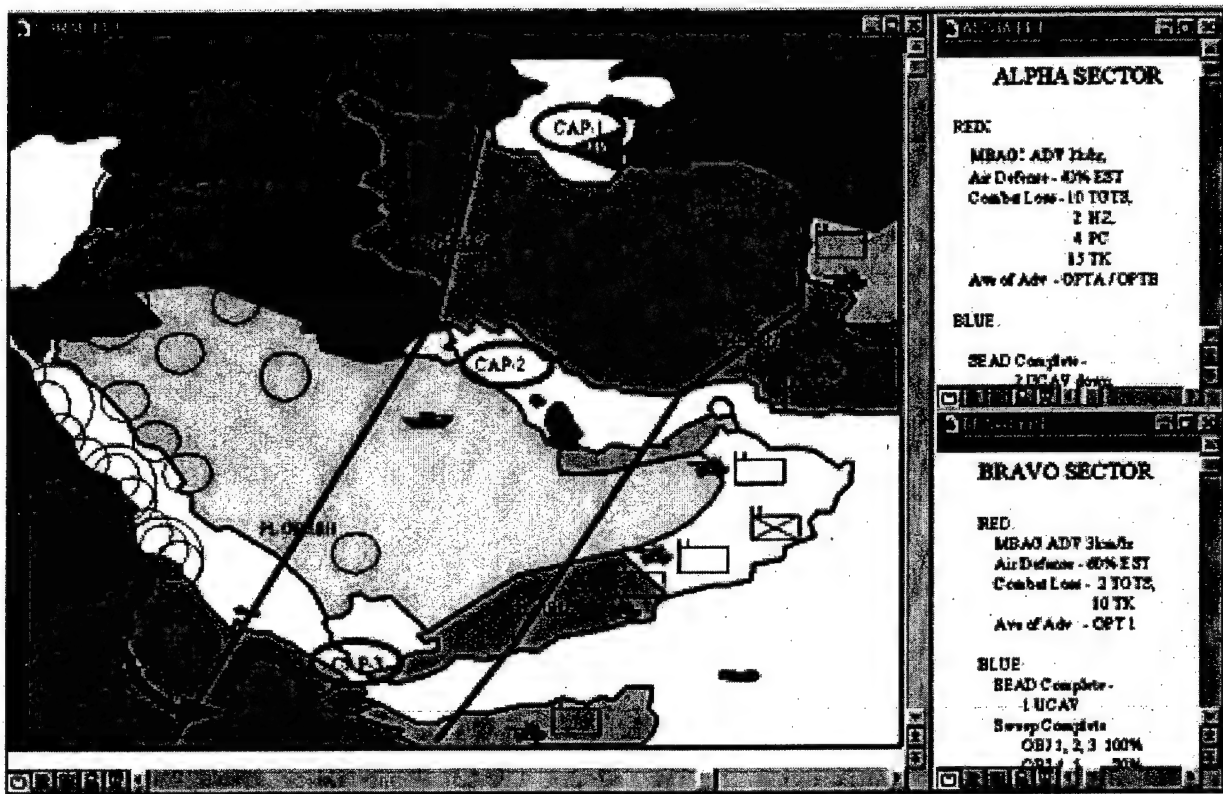
Figure III.6: Summary Situation Display (Left-hand Monitor)

On the right-hand side of the Summary Situation Display were two smaller windows -- each designated as containing composite data on Alpha and Bravo sectors, respectively. These windows were intended to represent the latest available status on operations in a given sector. As such, these displays had to present fused, filtered, and collated data as processed by the two operators participating in the simulated mission.
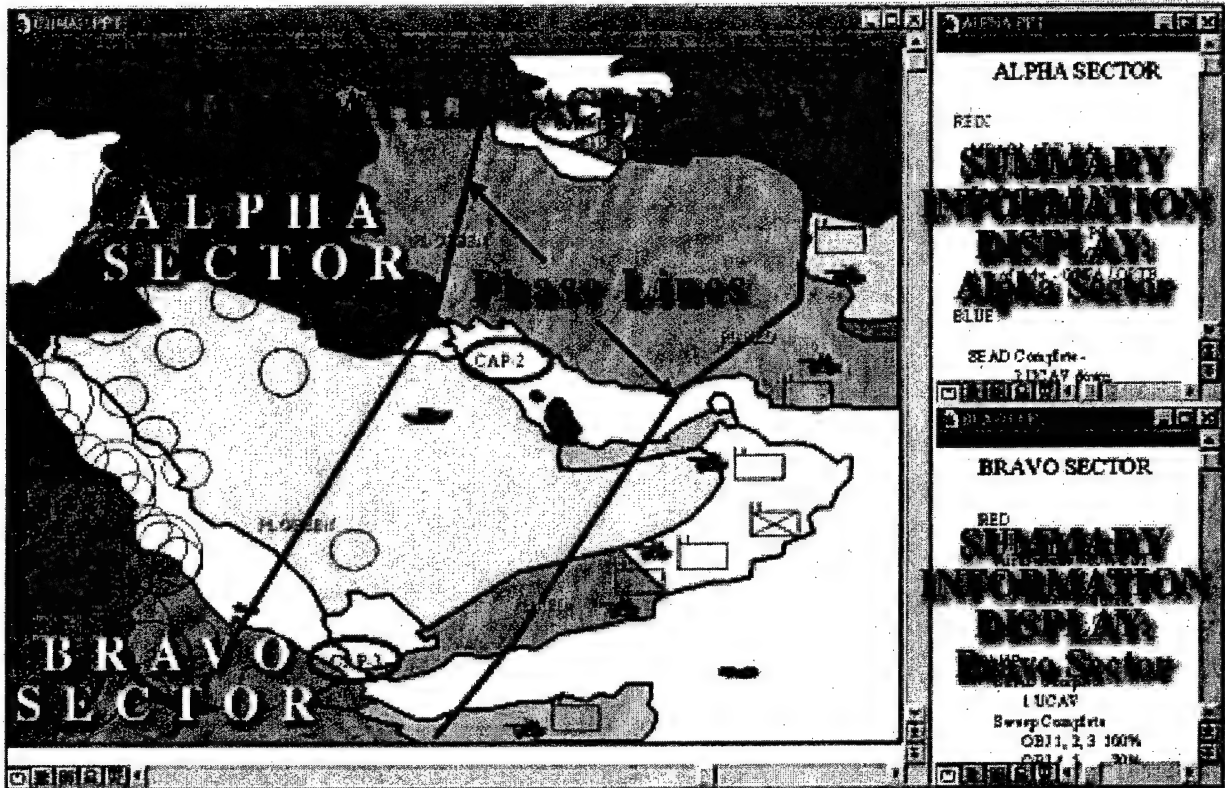
Figure III.7: Components of the Summary Situation Display

2. Individual Operator Display (Right - Hand Monitor)

In this section, the composition and configuration of each operator's individual or private on-screen workspace will be introduced. Figure III.8 illustrates the basic layout of the Individual Operator Display, and Figure III.9 annotates this layout with the nomenclature to be used in this section to introduce and explain the information display's intended utility.
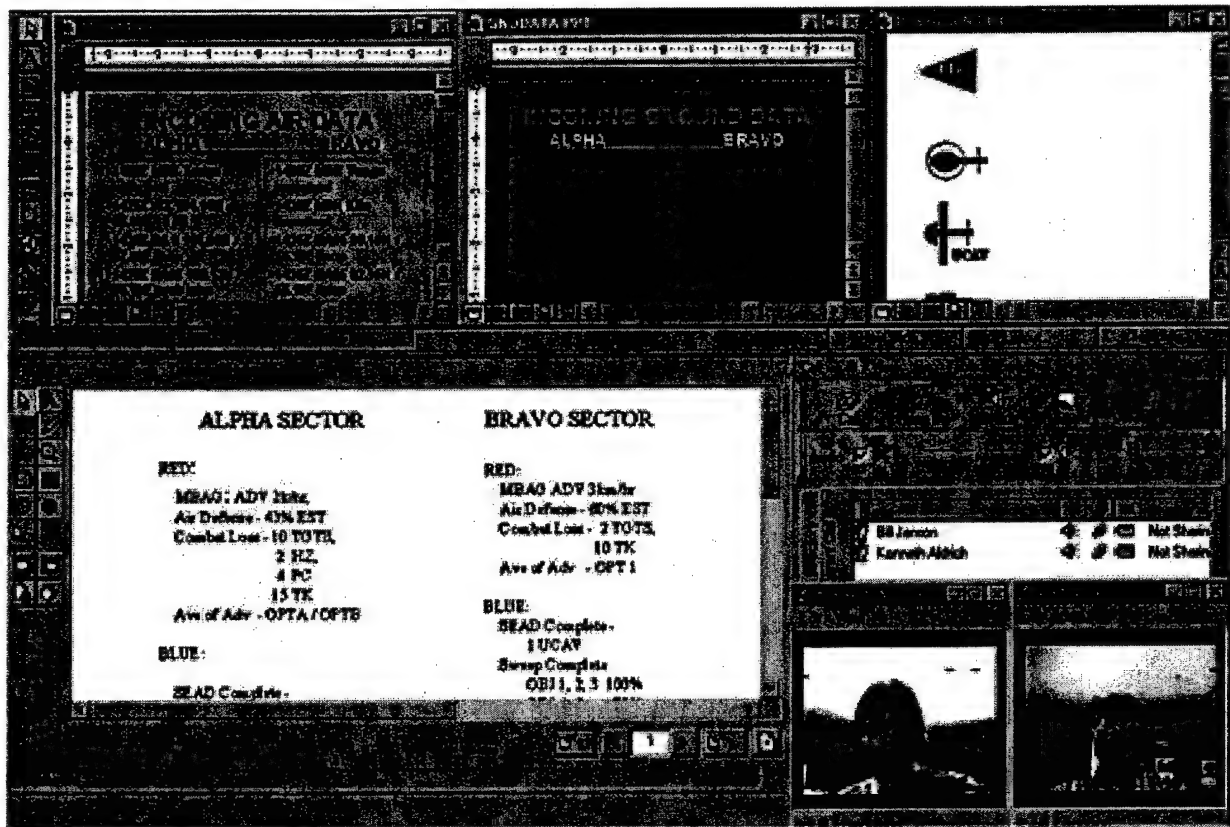
Figure III.8: Individual Operator Display (Right-hand Monitor)

The uppermost half of the Individual Operator Display contains a row of three windows essential to each operator's simulated task. In the upper left-hand portion of the Individual Operator Display are two windows -- each depicting incoming battlespace event data for the joint operation's air and ground components, respectively. Each operator had the ability to read and to "copy" the data from each of these windows. In terms of inputs to their tasks, the USAF operator's primary focus was the Air Event Data Stream, and the Army operator's primary focus was the Ground Event Data Stream. Each operator used his respective Data Stream window as the source for compiling overall battlespace status for his designated component (air vs. ground).

Because each of the operators had the additional task of compiling and forwarding status information by sector (i.e., Alpha vs. Bravo), both operators had to be accorded access to both Data Stream windows. In compiling the required sector-delimited summaries, the USAF operator had to augment information derived from the Air Event Data Stream with items derived from the Ground Event Data Stream, and vice versa. Even in the limited context of this demonstration, this clearly illustrates the manner in which organizational / operational factors (the task assignments) influence the provision of information to operators via their respective "interfaces."

In the upper right-hand corner is a window containing icons for a variety of air and ground operational elements (e.g., aircraft and tanks). Each operator had the ability to

38

"copy and paste" icons from this Platform Icon Window to the Summary Battlespace Display as a direct manipulative updating of asset status and resource allocation. As noted above with respect to the Data Stream windows and compiling status information, each operator had to have access to icons for both (i.e., air and ground) classes of operational elements to be manipulated on the Summary Battlespace Display. Again, this illustrates the manner in which tasking influences the affordances of each operator's "interface" to the overall BMC4I system of systems.

Figure III.9: Components of the Individual Operator Display

The lower half of the Individual Operator Display contains four windows which comprise the groupware component of the BMC4I demo. These windows (all realized via Microsoft NetMeeting) provided the joint work and communication space through which the operators collaborated in the simulated task.

In the lower left-hand corner was a Shared Whiteboard window. Each operator had read, write, and modify access to this shared resource. It was in the Shared Whiteboard window that the operators could individually add and jointly review their updates to the Summary Situation Display. In the extreme lower right-hand corner were two real-time video windows, in which the feeds from each operator's camera appeared. It was through these video windows that each operator could see the other. Above the video display windows were the Video Conferencing Controls by which each operator accessed and manipulated the communications channel between the two workstations.

3. Summary

At this point, we can now summarize the BMC4I setup with respect to the CSTL model of collaborative systems (cf. Figure III.3). In Figure III.10, the elements of the demonstration are organized with respect to the relative dependencies discussed above. The square boxes are used to illustrate specific units or technologies employed in the demonstration, and the oval boxes depict those capabilities or affordances supported by the units / technologies listed lower in the figure. These two types of elements allow us to illustrate the mappings for both the apparatus reviewed in section III and the operational scenario elements reviewed in sections IV and V. The use of three vertical "background bars" permits the illustration of how the logical / functional capacities of the BMC4I demo relate to the three-workstation platforms. The degree to which the technology and capacities "boxes" span the three vertical bars represents the degree to which the factors represented by those boxes span the three workstations employed in the demo.
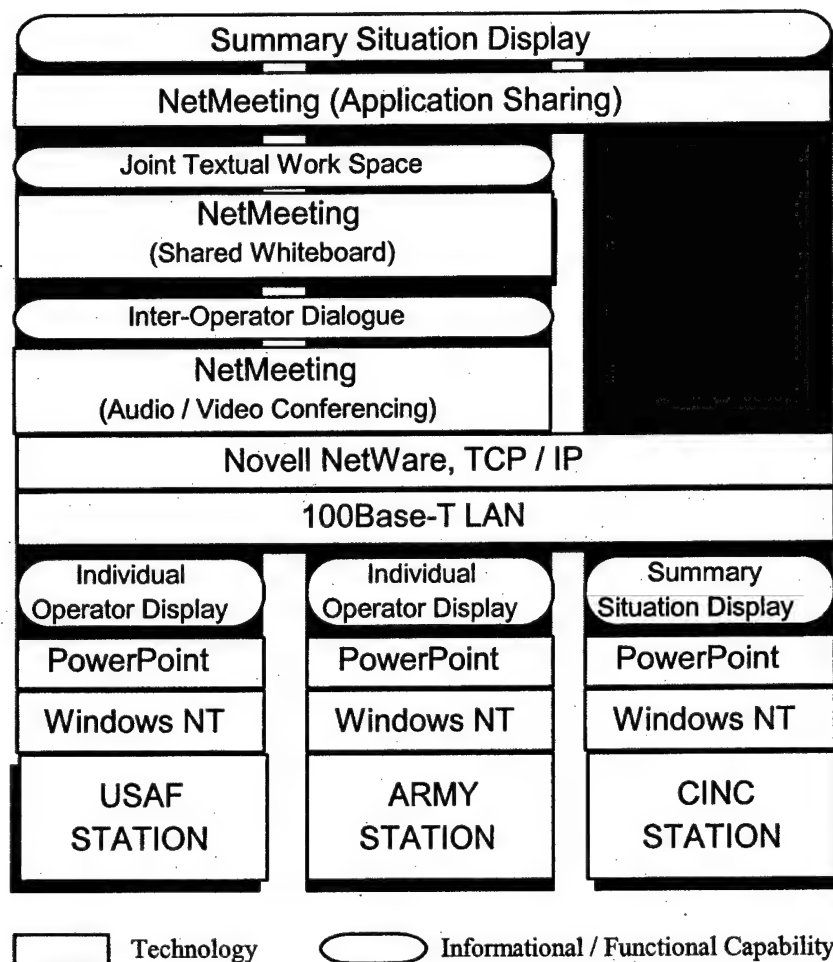

Figure III.10: The BMC4I Demo as an Instance of the CSTL Model

Figure III.10 provides a coherent framework for analyzing the topology and interdependencies among the elements comprising the BMC4I demo. Most importantly, it provides a basis for linking specific technical elements (e.g., workstations, software) to specific levels of collaborative activity afforded by a given subset of the overall technical system. Finally, Figure III.10 constitutes an illustrative application of the CSTL preliminary model (cf. Figure III.3), thus demonstrating an early result of CSTL theoretical work to date.

E. Groupware Issues Illustrated in the BMC4I Demonstration

The BMC4I demo setup illustrates multiple functional limitations of groupware software available on the market, as well as constraints which may derive from the specific manner in which groupware is installed and information streams are made available to users. Brief descriptions of some of these limitations are given in the remainder of this section.

1. The information being processed was not dynamic

There was no dynamic stream of new data arriving in any of the Alpha, Bravo, Air, or Ground windows. All these windows contained static, pre-loaded data items which were scripted in advance. In an actual operational context, one would hope that these could truly be data "streams", with new items arriving on a continuous basis. With respect to the detailed demo setup, this limitation derived from the fact that the event data streams were mocked up using PowerPoint. In actual applications, the same restrictions might appear for numerous reasons.

One obvious reason would be that the presentation of the data / information streams to end-users occurs through intermediary systems -- i.e., the original streams are not fed directly to the terminal workstations. This could occur where the BMC4I SOS is configured in such a way that these streams accrete to a data pool (e.g., a database management system) which users individually access. Intermittently "static" data streams could also result as a side effect of application locking for the sake of turn taking among collaborators.

To use the specific example of Microsoft NetMeeting, continuous incoming data streams could not have been handled in any case. The specific mechanism for data / information sharing (the Shared Whiteboard) accepts new items in real time from the collaborators. There is no mechanism by which a dynamically updating file could reside in the Shared Whiteboard per se. However, the application sharing capability (as was done to afford joint access to the PowerPoint files) could in principle provide a basis for joint access to some remote node or host on which such a file could be made available.

2. The operations allowed on the information were limited

Largely as a result of the static, pre-loaded nature of the data items comprising the majority of the demonstration displays, operator manipulations were effectively limited to "cut", "copy", and "paste" functions among windows. There were 3 specific such manipulations central to the demonstration:

1. transferral of items from the incoming Air and Ground data windows to the NetMeeting shared whiteboard (for joint viewing of work in progress
2. transferral of items from the incoming Air and Ground data windows to the Alpha and Bravo sector summary information windows on the Summary Situation Display (cf. Figures 6 / 7)
3. transferral of graphic icons from the Platform Icons window (cf. Figure III.9) to the Summary Battlespace Display window (cf. Figure III.7).

Even though these constraints derived from the use of PowerPoint mock-ups, they are not limited to the demonstration scenario. It is often the case that only a restricted set of manipulations are permitted in a shared information space -- something which derives from the fact that group software applications must commonly invoke application-specific protocols and mechanisms to allow common access and jointly-accessible manipulations on the shared information. Furthermore, the fact that there are few (if any) groupware suites providing the full range of collaborative functions means that multiple groupware applications might be in use at any one time. In such a case, the ability to perform even the modest "copy and paste" functions mocked up in this demo may depend on operating system capabilities rather than the capacities of the groupware applications per se.

3. Only dyadic interactions were represented in the demo

The only "players" capable of interaction and collaboration in the BMC4I demo were the two operators seated at the workstations. The simulated command center (with large-scale display of the summary information) did not have any operator / player on station, nor did it provide for any communication channel back to either operator. As such, the BMC4I arrangement can be characterized as "two players and one observer." Another factor limiting interactivity to two operators relates to Microsoft NetMeeting (the medium for video and whiteboard sharing). Although NetMeeting's shared whiteboard may be accessed by an arbitrary number of collaborators, the application's videoconferencing capacity is limited to "point-to-point" (i.e., between two given stations). Our decision to embed video conferencing in the demo therefore entailed a maximum of two operators.

This latter restriction is not unique to NetMeeting. Bandwidth, processor capacity, and other factors make such point-to-point constraints common among networked conferencing tools. To overcome such limitations often requires escalating the cost and complexity of the network infrastructure itself (e.g., with dedicated video routers) or segregating the audio / video conferencing functions onto a distinct parallel network infrastructure (e.g., adding a dedicated video network alongside the data network).

4. Behavioral adjustments were mandated by NetMeeting's affordances

The technological constraints of the specific groupware (NetMeeting) used in the BMC4I demo mandated that the operators act within the "envelope" of actions which the software could handle. For example, the shared whiteboard facility only allowed one participant to control the cursor (and hence manipulations) at a time. This induced a need to negotiate turn taking between the two operators -- a process which consistently introduced interruptions or delays in their work. Such turn taking (and its potentially problematical effects) is not unique to NetMeeting. It has been a long-standing issue in CSCW studies, and it remains an open issue for research.

5. Summary

The specific limitations and constraints above have been listed for the sake of explaining some particulars of why the BMC4I demonstration proceeded as it did. These types of limitations were not unique to the BMC4I demo setup, and must be faced in employing many COTS groupware products. As such, the demo substantively illustrated some of the key issues in linking and supporting collaborators through advanced information technologies. Research in (e.g.) HCI and CSCW has long addressed such topics. One might well wonder, then, about the extent to which these topics are still open areas for constructive research. We are convinced that there has been little progress to date along these lines, and that this relative deficiency can be explained with respect to the history of providing group IT support.

During the last 3 decades, the capacity for collaboration via computer networks has evolved in such a way as to mirror the topology of the technologies' deployment. By the end of the 1970's, one could afford users common access to files and limited joint interactivity, providing they were individually accessing a common hardware platform (e.g., a mainframe) via relatively "dumb" workstations. By the end of the 1980's, such abilities were afforded in the emergent desktop / LAN deployment paradigm to the extent that common software applications could operate across diverse individual workstations (e.g., PC's) connected by a coherent network infrastructure. Although end users had increased the scope of possible manipulations at the terminal interface, they were still constrained by issues of compatibility across their respective platforms. As we approach the end of the 1990's, we are seeing the emergence of viable software environments (e.g., Java) which are effectively platform-independent. At this initial stage, it is difficult to ascertain the extent to which current platform- and protocol-oriented features will continue to constrain collaborative utility.

The point is that the types of collaborative IT capacities built into the BMC4I demo (file sharing, shared whiteboard, video conferencing) is not really new. The fact of the matter is that there has been little (arguably no) new class of functionality made available to

team workers since the "old days." Instead, effort has been directed at continuing basic classes of collaborative capacity across the "divides" among successive paradigms of IT deployment. The research focus most relevant to CSTL's mission (interfaces for distributed collaboration) has not so much advanced over the last 20 years as it has simply recycled itself in response to shifting implementation modalities. As such, the work we propose to pursue is as yet undone even after all these years.

IV.
PLANNED ACTIVITIES

During FY 98 we plan to complete an experiment that will test the value to team performance provided by a joint functional interface that explicitly supports expert-level team and individual work processes. This interface will be contrasted with an alternative one intended to support distributed work but its design will not be model driven. Good human factors practices will be used in the development of both interface concepts. A suitable team task containing features of work representative of an ill-structured battle management work domain context will be developed and used in this experiment. Information content and work tools will be identical for both the experimental and control interfaces. Only the interfaces themselves will be different. We plan to use three person teams for this experiment. Adequate training will be provided prior to formal data collection to remove novice effects from work processes. The experiment will be designed such that team performance effects due to training, experience, and work-centered interface factors can be separated. Both process and outcome data will be collected and analyzed. Results will be used to refine the expertise and workspace models, the task and simulation environment, measurement methods, and features of the interface concept.

The research will be conducted in the Collaborative Systems Technology laboratory within the Human Effectiveness Directorate of AFRL. To support this research, additional lab development work will be required to produce a dynamic, interactive simulation task, as opposed to the canned data task used in the phase one BMC4I demo to gain familiarity with and knowledge about the capabilities and limitations of Microsoft NetMeeting as a collaborative work tool.

SUMMARY

This project was initiated in March 1997. It represents a new research activity that has been established to provide a scientific foundation for the development of human-network interfaces that facilitate the rapid ormation, maintenance, and mission performance of distributed teams operating in a fluid, fast-pace military context. During this initial six month period, we have made significant progress in four areas: (1) acquisition of knowledge about the complexities of the large-scale battlefield management, command, control, computers, and intelligence (BMC4I) work environment; (2) acquisition of knowledge about the emerging information technology infrastructure and products and how they relate to distributed, interactive, and shared work; (3) initial development of a theoretically based framework for use both to structure an empirical research program on the interaction between collaborative interfaces, in an IT environment, and team performance, and to provide a basis for model-based predictions of team performance; and (4) initial development of a laboratory to support the planned empirical research aspects of the project.

The work that confronts teams in the BMC4I context may best be characterized as involving significant real-time probleming solving. For distributed teams, problem solving is accomplished through an information technology network infrastructure. The human interfaces to this infrastructure, therefore, substantially influence problem-solving performance. We need a scientific understanding of this interaction. Our research framework addesses this issue from the perspective of what is known about experts who solve problems in complex real-world situations. We have presented a sketch of the framework which includes an introductory treatment of individual and team expertise and as a set of workspace models that identifies the range of process forms experts are believed to use. The model serves to both generate hypotheses about expertise and how the user interfaces (individiual and team focus) can be designed to facilitate effective and organized group work performance.

Based on our analysis we have established a conceptual model of the "user/team interface" with information network technology. This model helps to clarify the various layers and functional aspects of IT. Furteher, we used it to identify a joint functional interface to support teamwork that currently is not well formed in IT environments. One way to state the goal of this research program is to provide the basis for deriving design priniciples to be used in the design of the joint functional interface.

We created a demonstration of a distributed collaborative work concept in the BMC4I context. The main purpose for the demonstration was to aid us in checking out the interconnectivity of a hetergenous collection of hardware and software that define our network enviroment. The demonstration also provided a quick look at team issues for the BMC4I concept.

In a very short period of time, we have managed to put into place the basic infrastructure needed to support an empirical research program on collaborative work in an IT environment. During the next year, program emphsis will shift toward accomplishing an initial set of experiments designed to increase our understanding of expert behavior and to test hypotheses about the relation of user interface features and expert performance. We will also be developing our procedures for conducting subsequent large-scale experiments that can adequately differentiate performance effects due to the interface interaction from those due to interactions with experience and training factors.

REFERENCES

Bannon, L. J. [1991]. From human factors to human actors. In Greenbaum, J., and Kyng, M., Eds., *Design at Work: Cooperative Design of Computer Systems*. Hillsdale NJ: Erlbaum, 25-44.

Bennett, K. B. and Flach, J. M. [1992]. Graphical displays: Implications for divided attention, focused attention and problem solving. *Human Factors*, **34** (5), 513-533.

Bennett, K. B., Nagy, A. L. and Flach, J. M. [1997]. Visual displays. In Salvendy, G., Ed., *Handbook of Human Factors and Ergonomics*. New York: Wiley.

Chase, W.-G. and Simon, H. A. [1973]. Perception in chess. *Cognitive Psychology*, **4**, 55-81.

Chase, W.-G. [1986]. Visual information processing. In Boff, K. R., Kaufmann, L. and Thomas, J. P., Eds., *Handbook of Perception and Human Performance. Vol. II: Cognitive Processes and Performance*. New York: Wiley.

Dreyfus, H. L. and Dreyfus, S. E. [1986]. *Mind over Machine: The Power of Human Intuition and Expertise in the Era of the Computer*. New York: The Free Press.

Eggleston, R. G. [1988]. Machine intelligence and crew-vehicle interfaces. In Heer, E., and Lum, H., Eds., *Machine Intelligence and Autonomy for Aerospace Systems*. Washington D.C.: AIAA Press, 51-87.

Flach, J. M. and Dominguez, C. O. [1995]. Use-centered design: Integrating the user, instrument, and goal. *Ergonomics and Design*, pp. 19-24.

Flach, J. M. and Warren, R. [1995]. Low altitude flight. In Hancock, P. A., Flach, J. M., Cairo, J. K., and Vincente, K. J., Eds., *Local Applications of the Ecological Approach to Human-Machine Systems*. Hillsdale NJ: Erlbaum, 65-102.

Hewitt, B., and Gilbert, G. N. [1993]. Groupware interfaces. In Diaper, D., and Sanger, C., Eds., *CSCW in Practice*. Berlin: Springer, 31-37.

Klein, G. A. [1989]. Recognition-primed decisions. In W. B. Rouse, Ed., *Advances in Man-Machine Systems Research (Vol. 5)*. Greenwich CT: JAI Press, 47-92.

Klein, G. A. [1997]. *Implications of the Naturalistic Decision Making Framework for Information Dominance*. Fairborn OH: Klein Associates technical report.

Klein, G. A., Calderwood, R. and Clinton-Cirocco, A. [1986]. Rapid decision making on the fireground. *Proceedings of the 30th Annual Meeting of the Human Factors Society I*, 576-580.

Klein, G. A., Orasanu, J., Calderwood, R., and Zsambok, C. (Eds.) [1993]. *Decision Making in Action: Models and Methods*. Norwood NJ: Ablex.

Malone, T. [1985]. Designing organizational interfaces. *Proceedings of the CHI '85 Conference on Human Factors in Computer Systems*, San Francisco: ACM, 66-71.

Owens, Adm W. A. [1995a]. The emerging system of systems, *Naval Institute Proceedings*, May 1995, 35-39.

Owens, Adm W. A. [1995b]. Keynote Address, 1995 Military Operations Research Society Symposium, Annapolis MD: US Naval Academy, June 1995.

Owens, Adm W. A. [1995c] Introduction, in Johnson, Stuart E., and Martin C. Libicki (eds.). *Dominant Battlespace Knowledge: The Winning Edge*, Washington, D.C.: National Defense University Press, October 1995, 3-18.

Norman, D. A. [1986]. Interface. In Norman, D. A., and Draper, S., Eds., *User-Centered Systems Design: New Perspectives on Human Computer Interaction*. Hillsdale NJ: Erlbaum, 3-18.

Rasmussen, J. [1986]. *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering*. New York: Elsevier.

Rasmussen, J., Pejtersen, A. M., and Goodstein, L. P. [1994]. *Cognitive Systems Engineering*. New York: Wiley.

Regian, J. W. and Elliott, L. R. [1997]. *Intelligent Tutoring for Team Performance: Theory-based Development of an Enhanced Platform for Team Training and Performance Research*. Brooks AFB: Armstrong Laboratory working manuscript.

Shrobe, H. [1996]. ARPATech '96 Information Survivability Briefing presented at the ARPATech '96 Systems and Technology Symposium, Atlanta GA, May 22-24, 1996. Briefing slides available online via WWW at: http://www.ito.darpa.mil/ARPATech96_Briefs/survivability/survive_brief.html

Teichner, W. H. and Krebs, M. J. [1974]. Laws of visual choice reaction time. *Psychological Review*, 1974, 81, 75-98.

Thordsen, M. L., Klein, G. A. and Kyne, M. [1994]. *A Model of Advanced Team Performance*. Fairborn OH: Klein Associates technical report.

Wickens, C. D. and Carswell, C. M. [1995]. The proximity compatibility principle: Its psychological foundation and its relevance to display design. *Human Factors*, 37 (3), 473-494.

Woods, D. D. [1991]. The cognitive engineering of problem representation. In G. R. S. Weir and J. L. Alty, Eds., *Human-Computer Interaction and Complex Systems*. London: Academic Press, pp. 169-188.

Woods, D. D. and Roth, E. M. [1988]. Cognitive systems engineering. In M. E. Helander, Ed., *Handbook of Human-Computer Interaction*. New York: North-Holland, pp. 3-43.

Woodson, W. E. and Conover, D. W. [1964]. *Human Engineering Guide for Equipment Designs*. Berkeley: University of California Press.